SEISMIC PERFORMANCE OF AXIALLY LOADED CONCRETE ENCASED CFST WITH RECTANGULAR SPIRAL STIRRUPS

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Abstract— Concrete-filled steel tubular (CFST) columns have been widely used in high-rise buildings and long-span structures due to its many advantages, such as good seismic behavior, high bearing capacity and convenient construction. Moreover, compared with circular concrete encased CFST columns, square concrete encased CFST columns have the advantages of better bending capacity, simpler node structure, more regular building layout, etc., so it is more favored by architects in high-rise buildings and bridges. Concrete-encased CFST structures are fundamentally different than pure CFST structures, because there is a much wider range of confinement of the concrete in the box section as compared to the high degree of confinement in the inner CFST component. Columns with spiral stirrup alleviates the local buckling of steel tube, thereby improving both ultimate bearing capacity and ductility. To analyse the Seismic performance of axially loaded square Concrete encased CFST with helical stirrups and the failure mode, hysteretic energy dissipation capacity, skeleton curve, ductility factor, strength degradation, stiffness degradation of confined composite columns should be analysed. The parameters like thickness of steel tube, the pitch of spiral stirrups, and diameter of the spiral stirrups are considered.

Keywords— Helical stirrups, CFST, ductility factor

I. INTRODUCTION

Column is a vertical structural member, primarily subjected to axial compression, and it transmits the load from roof slab and beam, including its self-weight to the foundation. In the last few decades, the applications of CFST members are being increased in the construction industry due to their high load carrying capacity, good seismic performance, and easy construction. Large-scale building structures have become more common due to the use of Concrete filled steel tubular (CFST) members .CFST is a composite section formed by filling concrete into the hollow steel tube. CFST columns have better structural performance than reinforced concrete (RC) columns in terms of ductility and load carrying capacity. The outer steel tube of CFST is susceptible to corrosion especially under chloride environment. It has been found that corrosion caused significantly deterioration to the compressive and flexural strength of CFST column. The fire resistance of CFST column has been a concern as the outer steel tube nearly loses its strength. In recent years, a new composite column namely concrete-encased concrete filled steel tube (concrete-encased CFST) column is introduced. Compared with normal CFST column, concrete-encased CFST column has a higher capacity to resist fire, corrosion and has a higher durability, since the outer concrete served as covering layer for the inner steel tube. The rectangular spiral stirrups, they can avoid the wastage of steel that happens with the ordinary stirrups due to the presence of the hooks at their ends and they can provide stronger restraint to the core concrete and improve the ductility of the columns. Spirally reinforced columns has greater toughness, load carrying capacity and ductility as compared to the columns with ties.

II. OBJECTIVES

- To study the seismic performance of axially loaded Concrete encased CFST with rectangular spiral stirrups.
- To conduct a parametric study based on the pitch of rectangular spiral stirrups, diameter of the steel tube and thickness of the steel tube.

III. LITERATURE REVIEW

Various research studies are carried out for analysis and design of Concrete encased CFST Column. Researchers conducted the experimental and analytical studies on CFST Columns and rectangular spiral stirrups. Chao Hou et al (2018) Presents the analytical behaviour of concrete-encased concrete filled steel tubular members (concrete-encased CFST members for short) under the combined effects of compression and torsion. Typical failure modes are investigated, whilst the behaviour of RC and CFST components in the composite members are compared with those of individual RC members and CFST members under the same loading condition. Chengzhi Wang et al (2018) showed that the CFST column with reinforcing bars has a higher bearing capacity, more effective plastic behavior, and greater toughness. Guangzhao Fan et al (2018) proposed a new type of wall, named "spirally reinforced shear walls". Two CFST composite shear walls, two spirally reinforced shear walls and 1 RC shear wall were tested. The primary test parameter was the type and arrangement of the reinforcement. And to point out the influence of spiral stirrups. In the case of the same steel consumption, the bearing capacity and deformation capacity of the spirally reinforced shear wall specimens were better than that of the CFST composite shear wall specimens and the spirally reinforced shear wall exhibited significantly better energy dissipation capacity than that of the RC shear wall. Jingming Cai et al (2018) Presents an experimental study on the hysteretic behavior of ECC-encased CFST columns. Eleven specimens, including seven ECC-encased CFST columns and four concrete-encased CFST columns were tested under cyclic loading. Lin-Hai Han et al (2014) presented a finite element analysis (FEA Reviews the development of the family of concrete-filled steel tubular structures to date and draws a research framework on CFST members. The research development on CFST structural members in most recent years, particularly in China. Palash Dey et al (2019) Conducted finite-element (FE) and experimental analysis and to understand the behaviour of the different cross-sectional configuration of plain concrete and concrete filled steel tube (CFST) short columns. The researchers concluded that the ductility of the CFST column is significantly high compared to the concrete alone. Xiangbi Zhao et al (2020) demonstrated the effect of axial compression ratio on the ductility for HCESRS column and found that as the shear span ratio increases, the ultimate bearing capacity of the member decreases and the deformation capacity increases. Xin Zhang et al (2019**)** investigated seismic resistance capacity of steel reinforced high strength concrete (SRHC) columns with rectangular spiral stirrups and showed good seismic resistance capacity. The SRHC columns with rectangular spiral stirrups exhibited higher energy dissipation than the SRHC column with ordinary stirrup. Yu-Feng An et al (2015) **c**arried out a finite element analysis (FEA) and to analyze the behavior of the composite columns. The interactions between the outer concrete and the steel tube of CFST, as well as the core concrete and the steel tube of CFST are investigated. The differences of concrete-encased CFST columns, conventional CFST and RC columns are analyzed. Zongping Chen et al (2021) conducted an experiment to demonstrate the compressive behaviour compressive of spiral stirrup reinforced concrete-filled square steel tubular (SSRCFSST) columns. The test results show that the spiral stirrup has excellent cooperation ability with square steel tube and concrete, can effectively improve the non-uniform confine of square steel tube and enhance the confine effect on concrete.

IV.MODELLING OF CONRETE ENCASED CFST COLUMN WITH RECTANGUALAR SPIRAL STIRUPPS

A three dimensional finite element model of concrete encased CFST column is developed using ANSYS 21. The contact between each layer where provided using 3-D surface-to-surface. The details of the specimen 1 is shown in the table1. Figure 1 shows the geometry of concrete encased CFST column with the dimensions.

TABLE I: DETAILS OF SPECIMEN 1

Specimen	C 90 168 6
Width of foundation beam	400mm
Depth of foundation beam	500mm
Span of the foundation beam	1400mm
Axial load ratio	0.2
Diameter of stirrups	5.8mm

Pitch	90mm
Diameter of longitudinal bars	12mm
Size of the column	300 ×300mm
Diameter of steel tube	168mm
Thickness of steel tube	6mm
Span of column	1600mm
Steel plate dimension	450×300 mm

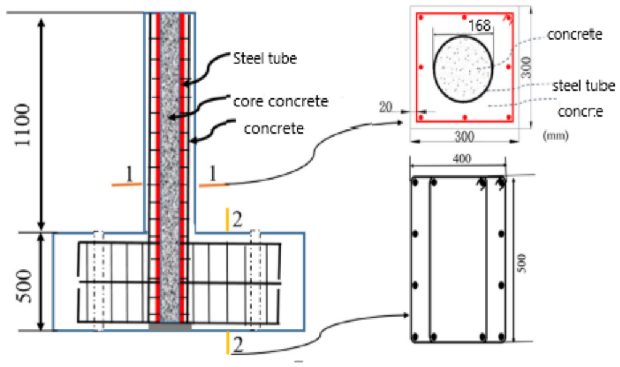

Fig 1. (a)Geometry of concrete encased CFST column (Jingming Cai et al (2018))

Table 2 shows the material properties used in material modelling of concrete encased CFST Columns with spiral stirrups.

TABLE II: MATERIAL PROPERTIES

Parameters	Value
Average compressive strength of concrete	41.1 MPa
Average young's modulus of	33.5 GPa
Yield strength of longitudinal bar	358 MPa
Yield strength of the stirrup	366 MPa
Yield strength of the steel tube	342 MPa

Finite element modelling of concrete encased CFST with rectangular spiral stirrups are developed and obtained Hysteresis curve skeleton curve, strength and stiffness degradation, energy dissipation and ductility values of specimens.

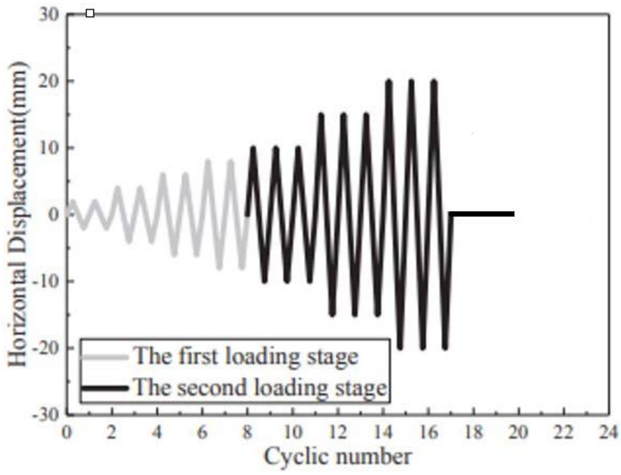

Fig 2. Loading history for all specimens(Jingming Cai et al (2018))

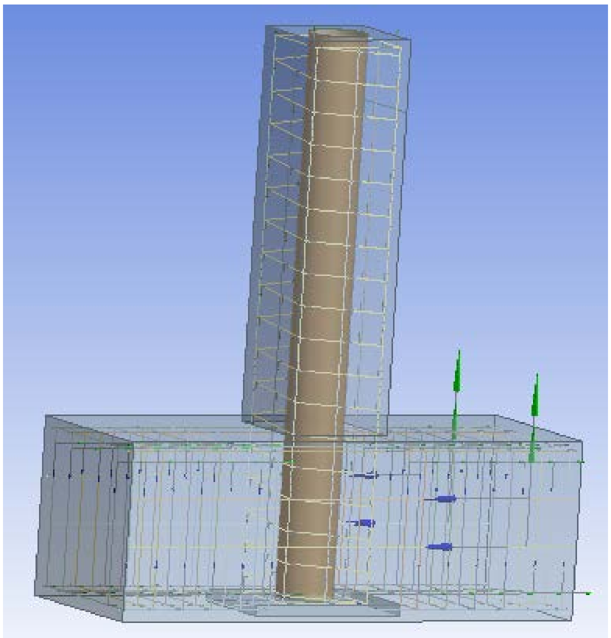

Fig 3. Model of concrete encased CFST with spiral stirrups

Each concrete-encased CFST columns was subjected to a constant vertical load and a horizontal cyclic load. The axial load can be calculated from axial load ratio. The horizontal cyclic load was applied with displacement increments. In first loading stage, there are two cycles for each displacement level and in second stage there are three cycles for each displacement levels. The cyclic loading history is shown in Fig.2. Figure 3 shows the finite element model of concrete encased CFST column and Figure 4 shows the reinforcements in the column.

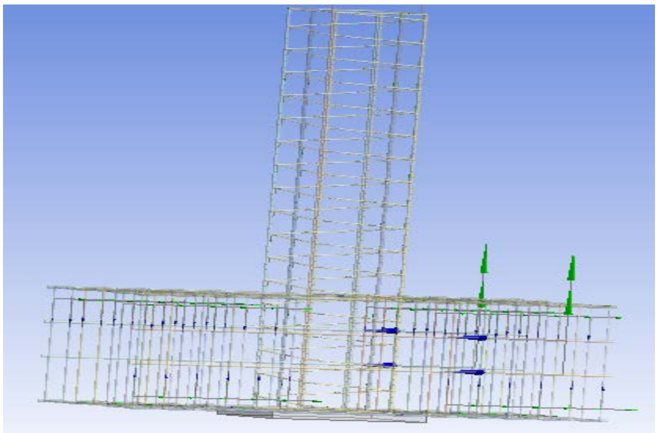

Fig 4. Model of reinforcements

The fixed support is provided to the bottom face of the foundation beam as shown in Fig.5.

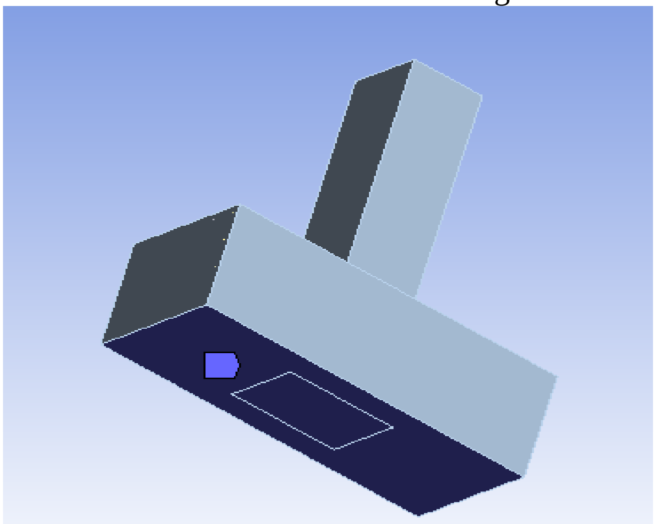

Fig 5. Model of reinforcements

Fig 6 shows the meshed model Fig 7 shows the meshed model of inner parts and Fig.8 shows the meshed model of spiral stirrups and longitudinal bars with steel plate. 25mm mesh size is provided for the specimen.

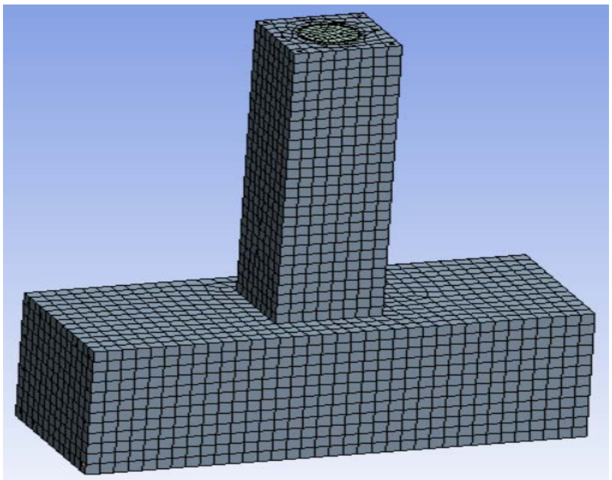

Fig 6. Meshed model of concrete encased CFST with spiral stirrups

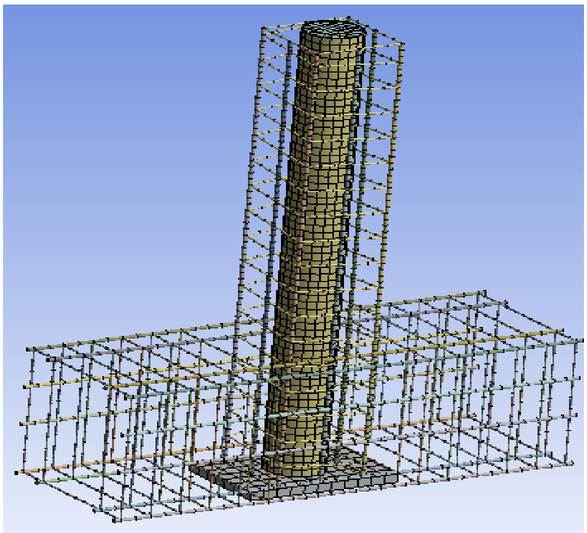

Fig 7. Meshed model of inner elements

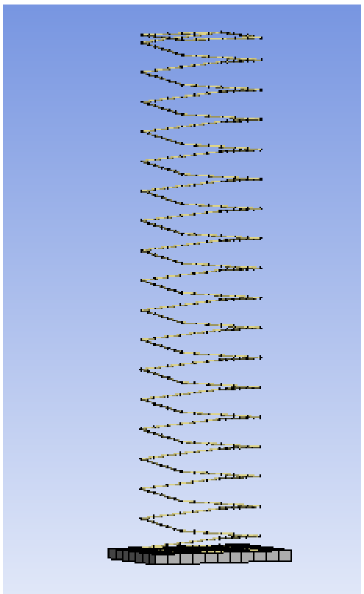

Fig 8. Meshed model of spiral stirrups and steel plate

V.RESU LT AND DISCUSSIONS

Concrete encased CFST column with rectangular spiral stirrups are analyzed in this study. And a parametric study has conducted based on the thickness of the steel tube, diameter of the steel tube and pitch of the spiral stirrups. Table 3 shows the dimensions of specimens selected for the study. Fig 9 and 10 shows deformed shapes of specimen and reinforcements respectively.

Figure 11 and 12 shows the hysteresis curve and skeleton curve of specimen C 90 168 6. C indicates concrete. The pitch of the stirrups are 90mm,the diameter of the inner steel tube is 168mm and the thickness of the steel tube is 6mm.the ultimate load obtained for this specimen is 421.6 KN indicates that the spiral stirrups which increases the load carrying capacity of the concrete encased column.

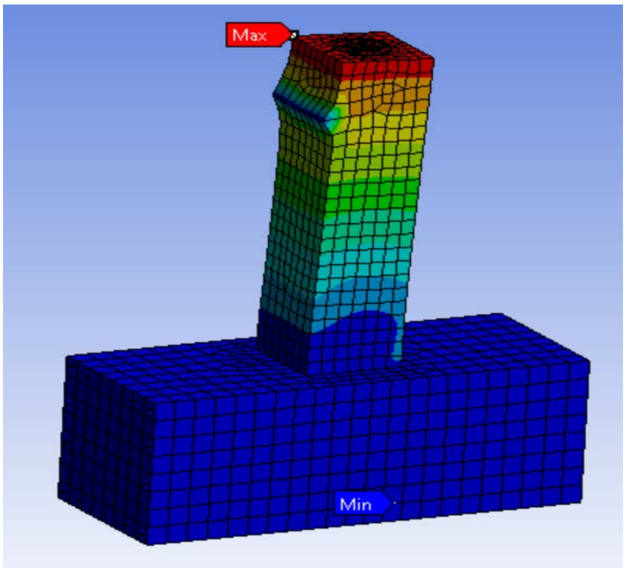

Fig 9. Deformed shape of specimen

The strength and stiffness deterioration of the specimen C 90 168 6 is shown in Figures 13 1nd 14. Both the values are decreases with increasing loading.

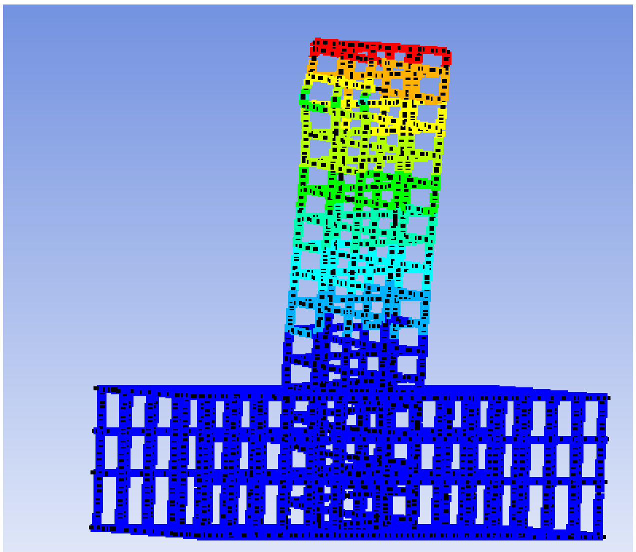

Fig 10. Deformed shape of reinforcements

The ductility factor (μ) was defined as the ratio of the ultimate displacement (Δu) to the corresponding yield displacement (Δy). The ultimate displacement (Δu) was defined as the displacement when the applied load decreased to 85% of the peak load. the ductility factor of the specimen is 5.72 is greater than or equal to 2 shows that the specimen 1 has good ductile behaviour.

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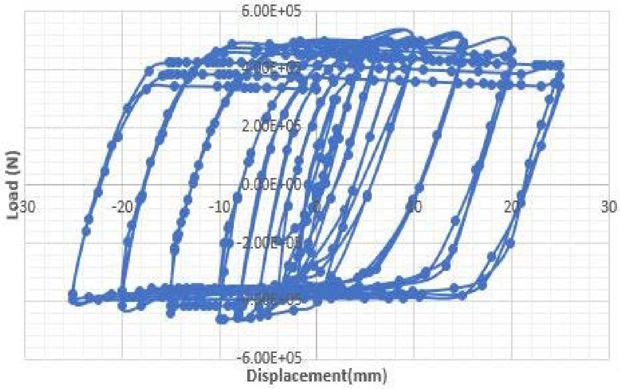

Fig 11. Hysteresis curve of Specimen C 90 168 6

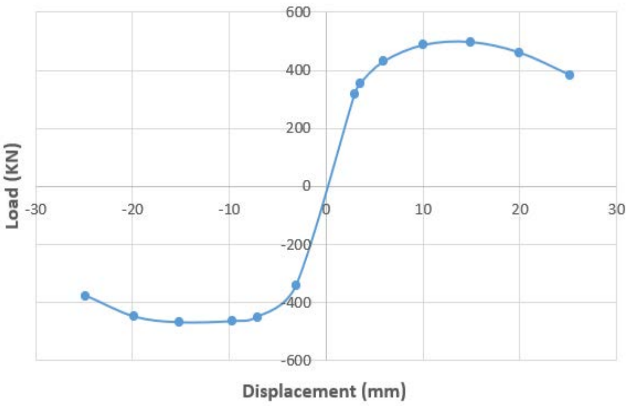

Fig 12. Skeleton curve for specimen 1(C 90 168 6)

The strength deterioration can be calculated using equation 1.

$$\lambda i = \frac{Vi1}{Vi3} \text{------------------} 1$$

(Jingming Cai et al (2018))

where λi is the deterioration coefficient in the ith cyclic loading, Vi,1 and Vi,3 are the ultimate load recorded in the first and third hysteresis loops, respectively.

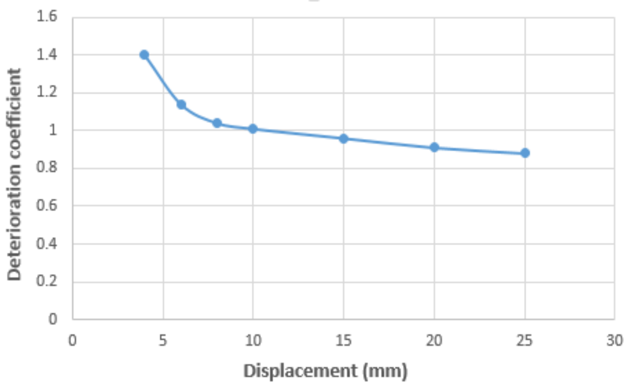

Fig 13. Strength deterioration for specimen 1

stiffness for the composite column represents the deformation resistance in response to the cyclic loading, which is defined as follows;

$$K = \frac{|+F_i| + |-F_i|}{|+\Delta_i| + |-\Delta_i|}$$ -------------2

(Jingming Cai et al (2018))

where + Fi and −Fi are the positive and negative ultimate loads during the first loading cycle at each load level, respectively, and + Δi and −Δi are the corresponding displacements for + Fi and −Fi.

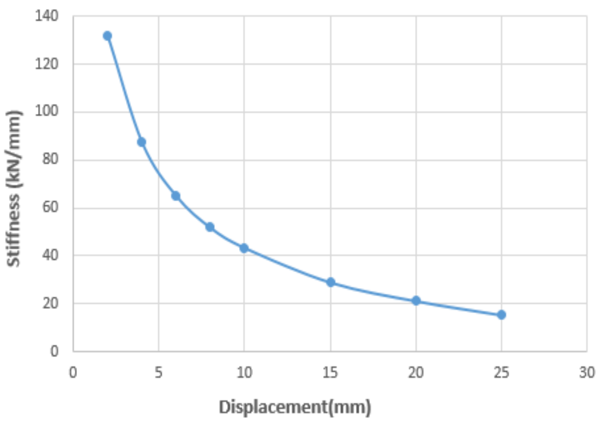

Fig 14. Stiffness deterioration for specimen 1

TABLE III: SELECTED PARAMETERS AND DIMENSIONS

concrete specimen	Pitch of the spiral stirrups in mm (s)	Thickness of the steel tube in mm (t)	Diameter of the steel tube in mm (D)
1	90	6	168
2	90	10	168
3	90	6	180
4	90	6	156
5	60	6	168
6	120	6	168

Fig 15 and 16 shows the hysteresis and skeleton curve of specimen 2 (C 90 168 10).here the analysis can be carried out by changing the thickness of the inner steel tube. Fig 17 shows the stiffness deterioration of the specimen 2.the stiffness value of specimen 2 is higher than specimen 1.ie.the Stiffness is increases with increasing thickness of the steel tube.

Fig 18 shows the strength degradation curves of the specimen's 1 and 2.graph shows that the thickness has a negligible influence on the deterioration coefficient of Concrete-encased CFST columns during beginning and the deterioration coefficient of specimen 2 is greater than specimen 1

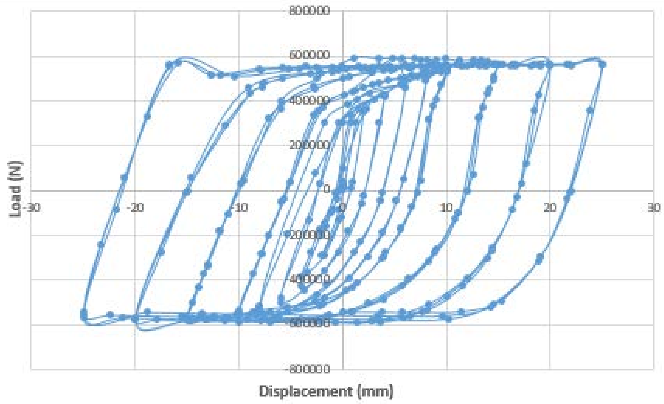

Fig 15 Hysteresis curve of Specimen C 90 168 10

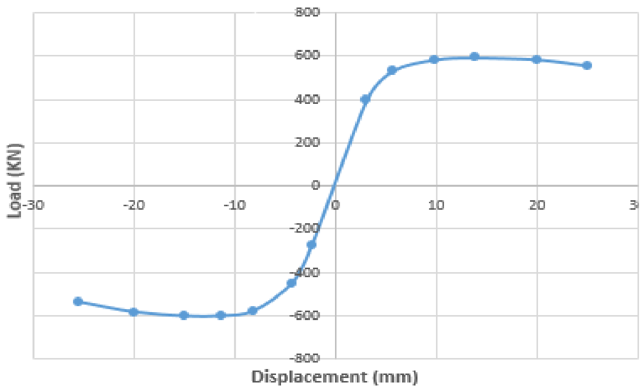

Fig 16. Skeleton curve for specimen C 90 168 10

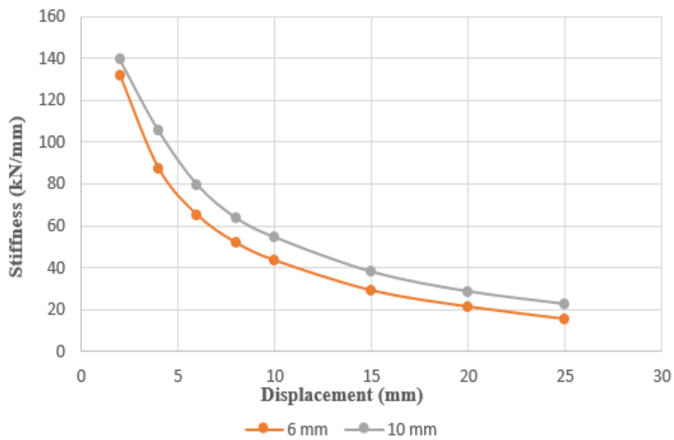

Fig 17 Stiffness deterioration for specimens with thickness of the steel tube

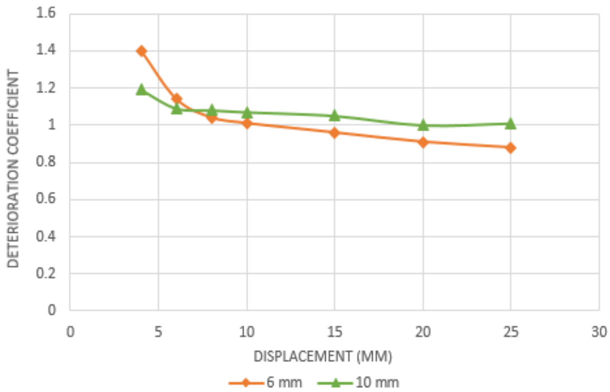

Fig 18 Strength deterioration for specimens with thickness of the steel tube

Figures 19 and 21 shows the hysteresis curves of the specimens C 90 156 6 and C 90 180 6 respectively.fig 20 and 22 shows the corresponding skeleton curves of the specimens.the ultimate load carrying capacity of the specimen is increses with increasing the diameter of the column.

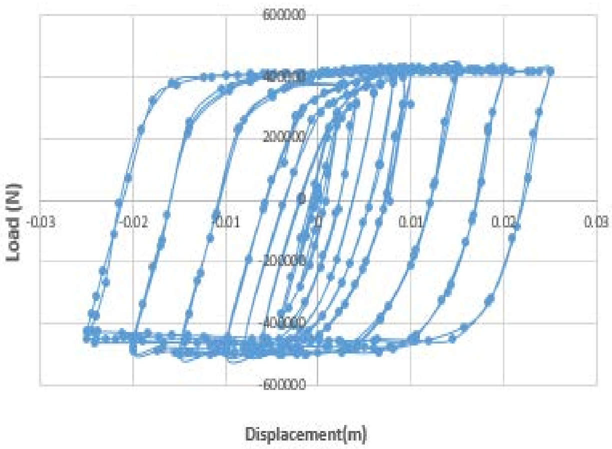

Fig 19 Hysteresis curve of Specimen C 90 156 6

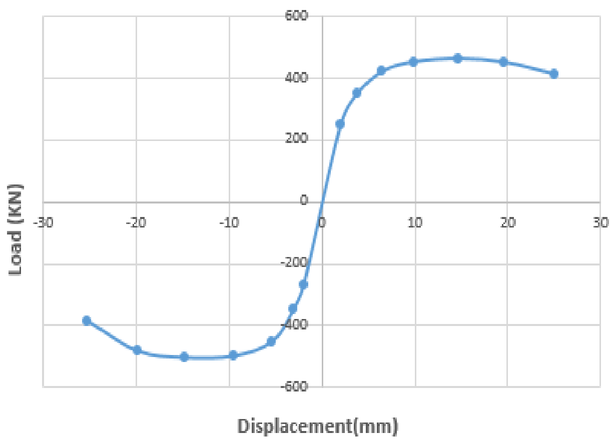

Fig 20. Skeleton curve of Specimen C 90 156 6

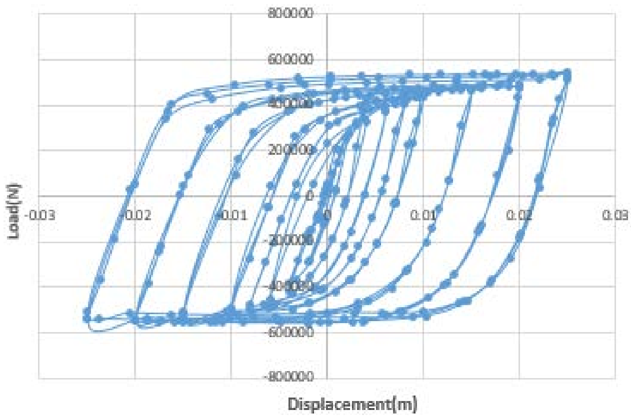

Fig 21 Hysteresis curve of Specimen C 90 180 6

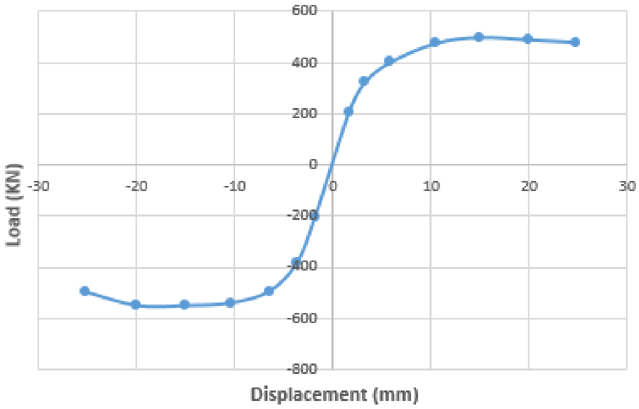

Fig 22 Skeleton curve of Specimen C 90 180 6

The Stiffness for C-90-180-6 is higher than that C-90-168- 6 and C-90-156- 6, which is shown in Fig. 23.but in the case of strength degradation of the specimens, the increase of steel tube diameter could influence the deterioration coefficient from the very beginning and the deterioration coefficient of 180 mm diameter steel tube column specimen is higher than that of 168mm and 156m diameter steel tube column specimens.

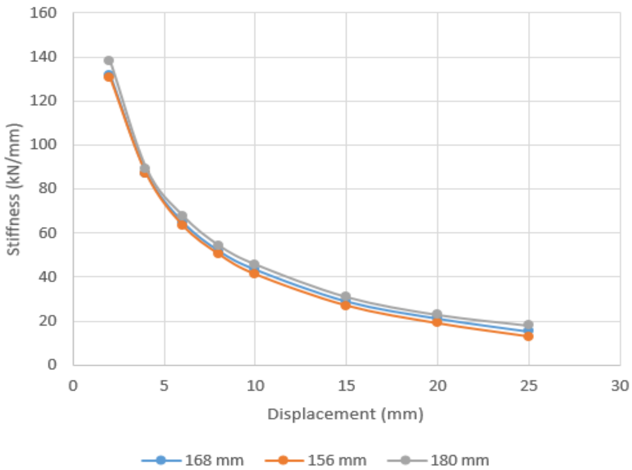

Fig 23. Stiffness deterioration for specimens with diameter of the steel tube

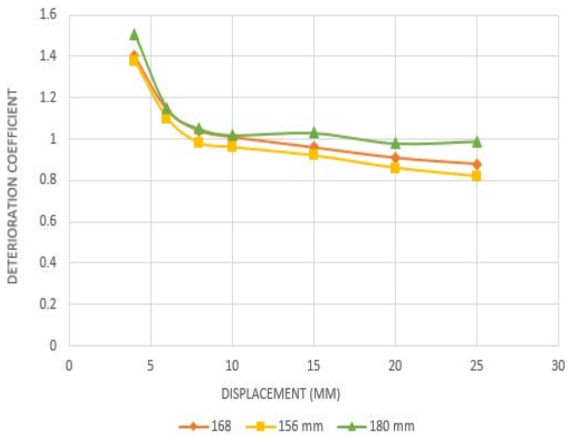

Fig 24. Strength deterioration for specimens with diameter of the steel tube

Figures 25 and 27 shows the hysteresis curves of the specimens C 60 168 6 and C 120 168 6 respectively.fig 26 and 28 shows the corresponding skeleton curves of the specimens.the ultimate load carrying capacity of the specimen is increses with decreasing the pitch of the spiral stirups in the column.

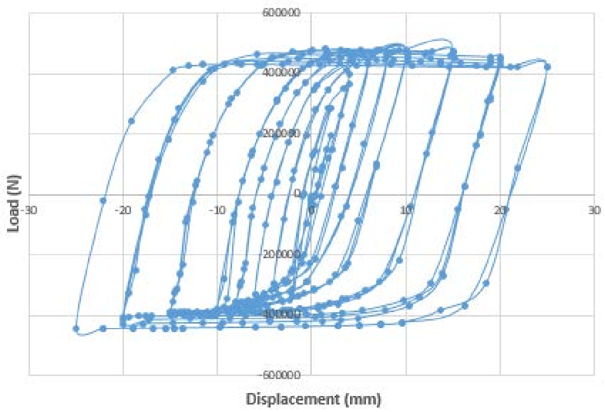

Fig 25 Hysteresis curve of Specimen C 60 168 6

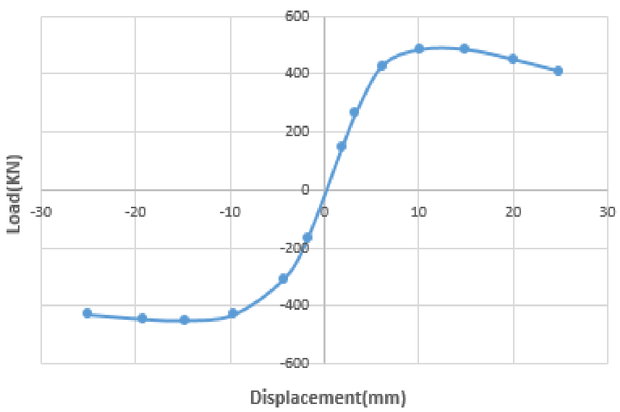

Fig 26 Skeleton curve of Specimen C 60 168 6

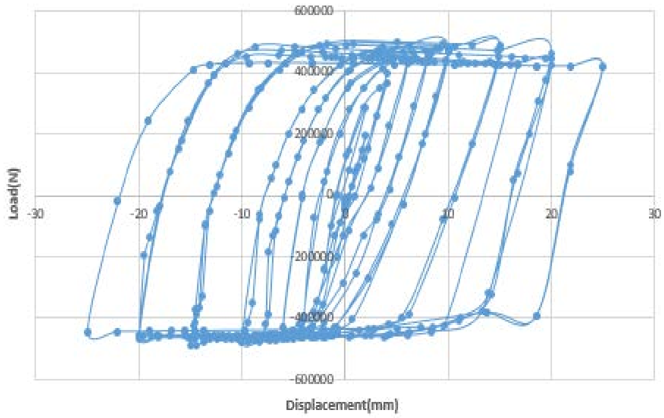

Fig 27 Hysteresis curve of Specimen C 120 168 6

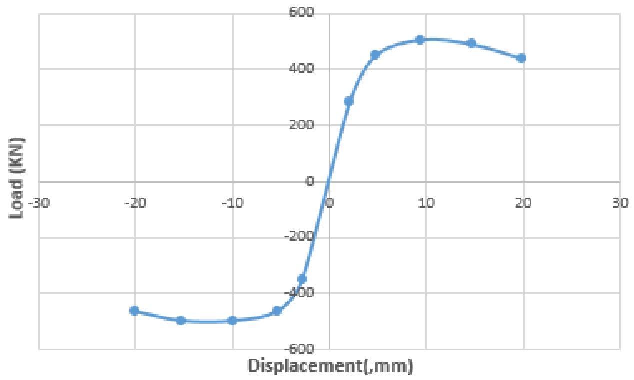

Fig 28 Skeleton curve of Specimen C 120 168 6

The Stiffness for C-60-168-6 is slightly higher than that C-90-168- 6 and C-120-168- 6, which is shown in Fig. 29.but in the case of strength degradation of the same specimens, the Stirrup spacing has a negligible influence on the deterioration coefficient of columns during the initial stages and deterioration coefficient of 60 mm pitch is higher than that of 120mm and 90mm pitch.

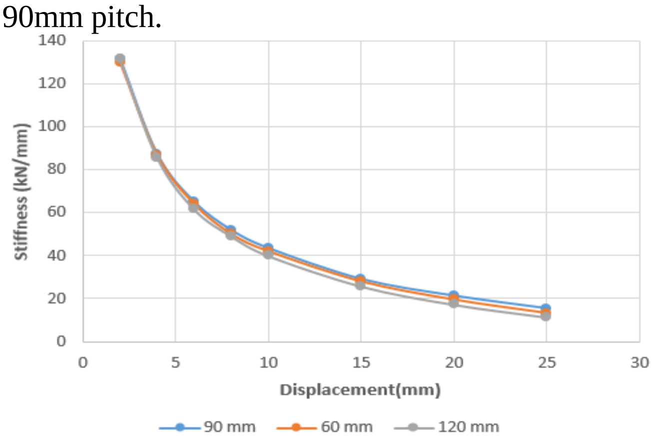

Fig 29 Stiffness deterioration for specimens with pitch of the stirrups

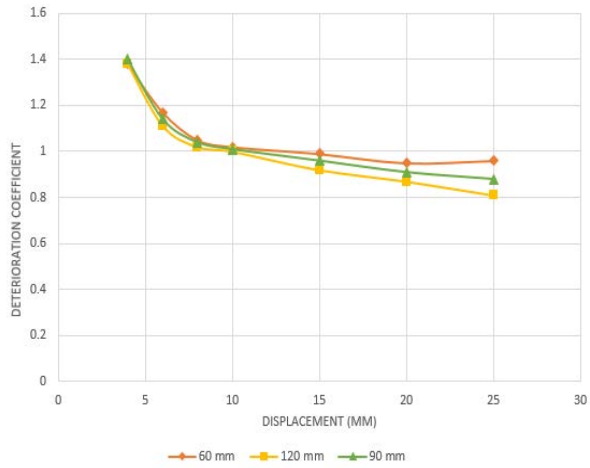

Fig 30 Strength deterioration for specimens with pitch of stirrups.

TABLE : IV DUCTILITY FACTOR FOR ALL SPECIMENS

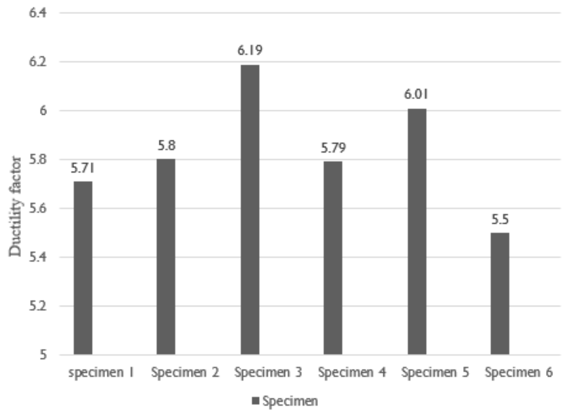

Fig 31 Ductility factor for all specimens

Energy dissipation performance is expressed by equivalent viscous damping coefficient *he*, which is defined by equation 3. Fig 32 shows the energy dissipation of all specimens. The energy dissipation coefficient values of the specimens are comes in the allowable range (≥0.1).

$$he = \frac{S_{ABCD}}{2\pi(S_{\Delta OBE}+S_{\Delta ODF})} \quad ....3$$

(Sujian Yu et al (2020))

Where, S_{ABCD} is the area surrounded by hysteresis loop, and $S_{\Delta OBE}$ & $S_{\Delta ODF}$ are the triangle surrounded area.

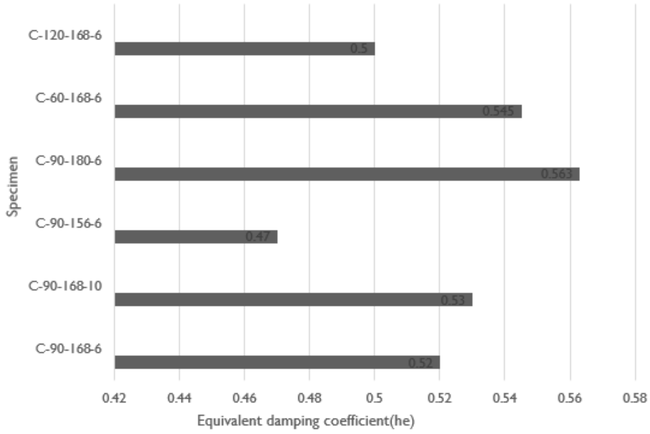

Fig 32 Energy dissipation for all specimens

The ductility factor of all the specimens are within allowable range of ≥2. Ductility of concrete encased CFST columns with spiral stirrups are greatly influenced by diameter of the steel tube. The ductility values of the specimens

Specimen	Ductility factor (μ)
1(C 90 168 6)	5.71
2(C 90 168 10)	5.8
3(C 90 180 6)	6.19
4(C 90 156 6)	5.79
5(C 60 168 6)	6.01
6(C 120 168 6)	5.5

are shown in table 4.comparison of the ductility values are shown in Fig 31. Ductility value of the specimen is increases with increase of steel tube diameter, thickness and decrease of pitch of the spiral stirrups.

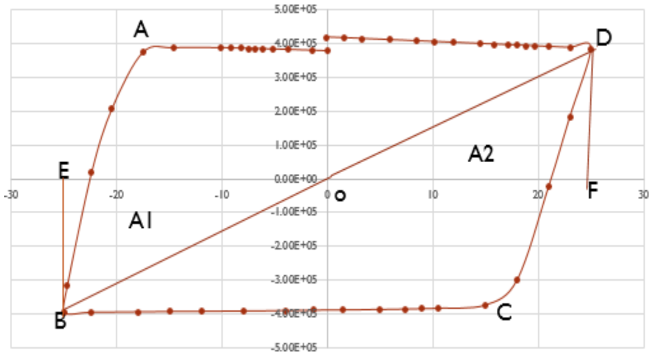

Fig 33 Hysteresis loop for finding the area

VI. CONCLUSIONS

In this work the analysis of concrete encased CFST with rectangular spiral stirrups have been studied numerically. Hysteresis curve, skeleton curve, strength and stiffness degradation, energy dissipation and ductility values of specimens where found out for different parameters. The following conclusions were drawn from this work.

- Spirally reinforced concrete-encased CFST columns has higher ductility, load carrying capacity, energy dissipation as well as a lower strength and stiffness deterioration than concrete-encased CFST columns with normal stirrups.
- When the steel tube diameter is increasing to 180mm, the ductility factor become 7.7 % higher than main specimen.
- Decreasing the pitch of the stirrups to 60mm the ductility factor is 4.9 % higher than main specimen.
- The energy dissipation coefficient values of the specimens are comes in the allowable range (≥0.1) for RC [Eurocode 3 (EC3).Design of steel structures Part 1-8: Design of joints].
- By considering thickness of the steel tube, pitch of the stirrups and diameter of the steel tube, the energy dissipation is 6% higher than main specimen when the diameter increased.
- The deterioration coefficient for 60mm pitch, 180mm diameter and 10mm thick steel tube specimens are 13%, 11.1%, 12.8% higher than that main specimen respectively.
- The stiffness of 60 mm pitch and 180mm diameter, 10mm thick steel tube specimens are 11%, 14.5% and 31.76% higher than main specimen respectively.

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