Original scientific article
http://dx.doi.org/10.59456/afts.2023.1528.029B

CONVERGENCE PROBLEMS WITH ANSYS'S SOLID 65 FINITE ELEMENT IN CONCRETE-FILLED TUBULAR (CFT) COLUMNS AS A CASE STUDY

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ABSTRACT

Using limited materials for numerical modeling of structural samples and comparing the behavior of samples with each other in order to reduce the number of straw test samples in order to reduce laboratory costs is one of the best methods today. ANSYS is one of the finite element software that is used for modeling reinforced concrete elements by Solid65 element. As a case study, a concrete-filled steel column under cyclic loading is examined and the best value for the Crushed Stiffness Factor (CSTIF) parameter that is one of Solid65 element parameters is suggested to confirm the modeling. By investigating the results, it can be concluded that this parameter is one of the most important factors that plays a significant role in convergence in ANSYS software for modeling CFT columns.
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Keywords: *Convergence problem, ANSYS, SOLID65, Crushed Stiffness Factor, CDTIF, concrete-filled steel column, cyclic loading*

INTRODUCTION

In order to compare the modeling results of samples with different Crushed Stiffness Factors (CSTIF) and to choose a appropriate coefficient to match the results of laboratory test samples with numerical samples, this study should be done on a reinforced concrete member as a case study. Since concrete-filled steel columns have been used especially in tall buildings, bridges and special and important structures in recent years due to many advantages which includes suitable ductility and strength with less volume and weight compared to common reinforced concrete columns, , this case study has been done on CFT columns.

In order to numerical modeling of the CFT columns in ANSYS software, many studies have been done. Abedi et al. in 2008 presented a new section by using internal longitudinal symmetric stiffeners in the inner part of the steel wall of the circular and octagonal columns. This new section has led to an increase in the strength and ductility of the section under axial and seismic loading [1]. Hsiao et al. in 2015, Wang et al. in 2016 and Aghdamy et al. in 2017 by examining the cross-section of a tubular steel column with two layers of internal and external steel walls (with a circular cross-section) that were filled with concrete. By loading these columns under the effect of constant axial load and seismic load, they concluded that by using the internal steel wall in addition to the external steel wall, it is possible to increase the resistance of the section against applied loads [2,3 and 4]. Zhou and Wenchao in 2016 by examining the double-skin steel wall section with a circular inner steel wall inside the section with a rectangular outer steel wall under axial and seismic loading found that the use of this new section increased ductility and strength [5]. Hassaneina et al. in 2018 and Vernardos and Gantes in 2019 compared and investigated the types of double- skin steel walled sections with the combination of rectangular and circular steel walls, both in the form of external walls and in the form of internal walls, under lateral loading [6,7]. Zheng et al. in 2018 investigated the sections of two concrete-filled tubular steel columns.

They have investigated the effect of strength of core concrete and the influence of the slenderness factor on the ultimate strength of the column. In this research, the results have shown that double-skin concrete-filled steel columns with slenderness factor greater than 60 have had a lower lateral load capacity [8]. Chen et al. in 2019 have investigated the CFT columns with octagonal section of steel wall and concluded that this section has a high-energy absorption capability [9]. In 2019, Wang et al. studied the seismic behavior of a square concrete-filled steel tube (CFT) column when subjected to cyclic stress. Nine large-scale square CFT columns were studied, each with a distinct shear stud configuration and axial compressive load ratio constructed according to engineering practice requirements.

The damage mechanism, force-displacement relationship, deformation capacity, stiffness degradation, and energy dissipation capability of these specimens were all reviewed. The axial compressive load ratio has a considerable influence on the hysteresis loops of the square CFT columns, according to test data. In specimens with a low axial compressive load ratio, the shear stud significantly improves local buckling of the steel tube [10]. In a cyclic loading test of six full-sized square columns, including one traditional reinforced concrete (RC) column and five steel tube-reinforced concrete (STRC) composite columns, Zhang et al. in 2019 investigated the cyclic behavior of steel tube-reinforced, high-strength concrete columns with high-strength steel bars.

The test's main characteristics were the cross-sectional form of the inner steel tube, the strength matching of the outer concrete and the concrete core, and the presence of steel fiber in the outer concrete. The addition of steel fibers to concrete matrix can improve the tensile behavior and hinder cracking of concrete, thereby reducing the damage of concrete. Besides, it can slow down the slope of descending branch on the compressive stress-strain curves of concrete. In comparison to RC columns, steel fiber reinforced high-strength STRC composite columns showed improved seismic performance, according to the study. Steel fibers in exterior concrete successfully decreased the degree of damage and increased the specimens' ductility, robust ability, and energy dissipation capacity [11].

Wang et al. tested six stiffed CFDST beam-columns under continuous axial load and cyclic lateral load in the year 2020. The axial load level and the hollow section ratio were the main test parameters. All specimens' load, deformation, and strain were measured and studied. In terms of lateral resistance, ultimate displacement, ductility, and energy dissipation ability, the effect of parameters was addressed. They discovered that under cyclic stress, the stiffened specimens had a good energy dissipation capability. Additionally, the longitudinal stiffeners might significantly decrease local tube wall buckling. Stiffened CFDST members have stronger ductility and energy dissipation capability than unstiffened CFDST members [12].

In this study, a concrete-filled steel column is tested under seismic loading and compared with the results of numerical modeling with different Crushed Stiffness Factor (CSTIF) under the same loading conditions. The purpose of this research is to find the best value for the Crushed Stiffness Factor (CSTIF) factor to match the numerical modeling results with the experimental results.

SECTION FOR CONCRETE-FILLED STEEL COLUMN AS A CASE STUDY

The cross section of the column that we want to examine is shown in Figure 1. The steel wall have an inner diameter of 0.254 m and a thickness of 0.008 m, while the columns have a length of 2 meters. As a result, the diameter of outer steel wall is 0.27 m.

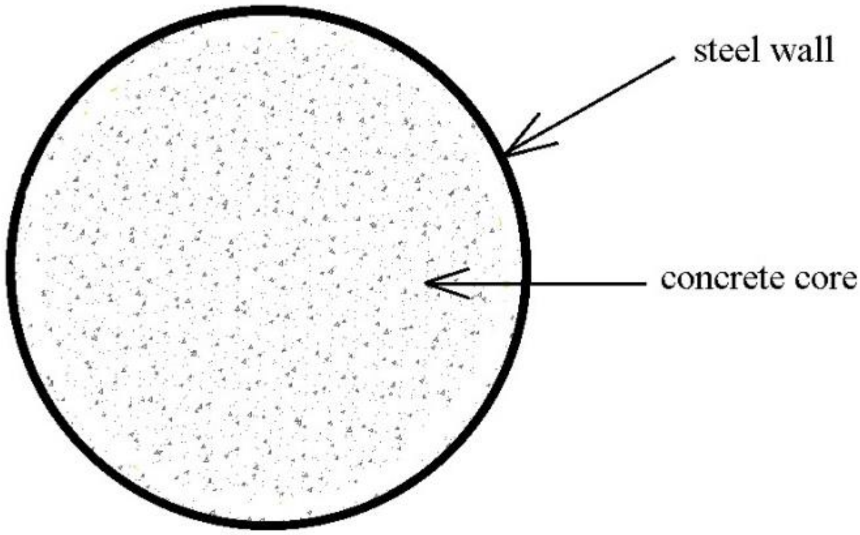

Figure 1. Proposed section of CFT with internal steel mesh located in nearby steel wall

FINITE ELEMENT MODELING OF CFT COLUMN

ANSYS finite element software has been used to model concrete-filled steel column. Furthermore, SOLID65 three-dimensional element has been used to model core concrete. This element is defined by a hexagon, eight nodes with three translational degrees of freedom in each node.

This solid element may fracture under tension and crush in compression, as well as deform plastically and creep. Moreover, SOLID 45 element has been used to model the steel wall. This element is compatible with the steel wall's shell element and the concrete core's isoperimetric solid element.

Plasticity, stress stiffening, large deflection, and huge strain capacities are all features of this element. The shape and coordinates of the nodes in the element coordinate system are shown in Figure 2 [13]. With the assumption of the cleanness of the steel and sufficient adhesion of the core concrete to the steel (perfect bond with no slip assumption), the coincident nodes of the steel and the core concrete can be connected to each other by merging [15]. In this research, no contact element was used and assumed a perfect bond by merging the coincide nodes of steel and core concrete.

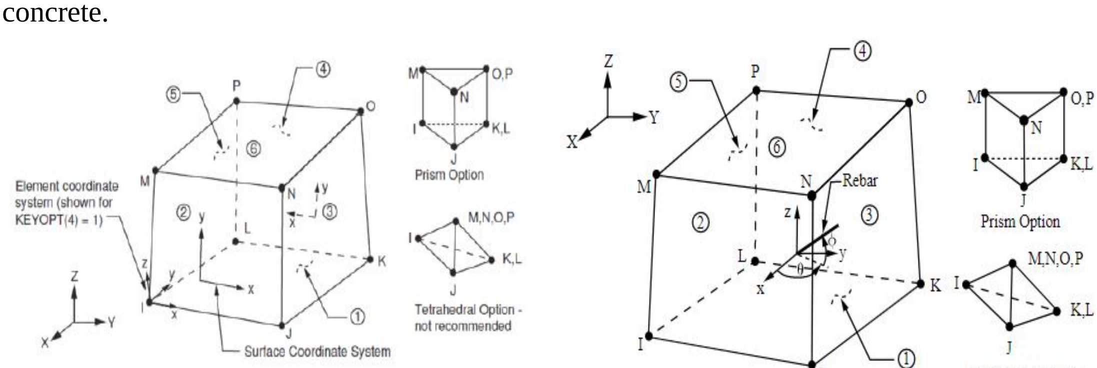

Figure 2. Geometry and node coordinate of elements used in modeling

The behavior of materials used in the modeling of the samples of columns is indicated in Figure 3 [1].

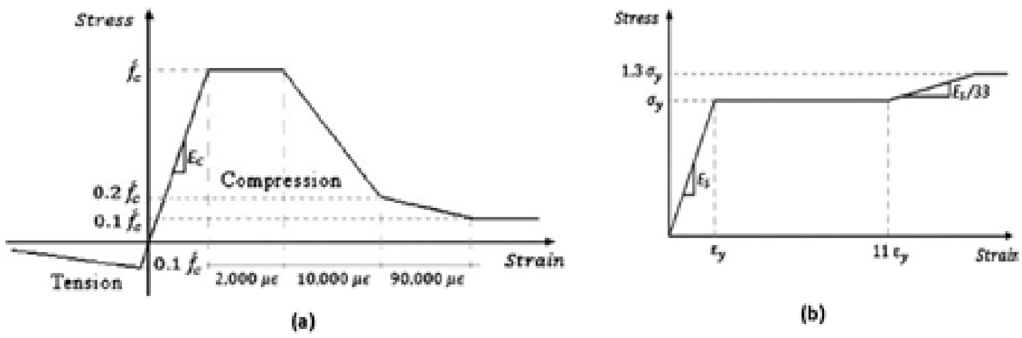

Figure 3. Stress-strain relationship curves for the a) core concrete and b) steel in steel wall and steel mesh

VALIDATION OF FINITE ELEMENT MODELING OF LABORATORY SAMPLES

Numerical results obtained from the nonlinear analysis and the experimental results of CFT columns have been compared with each other. Furthermore, after applying 30 percent of the column's nominal load bearing capacity as an axial load, lateral cyclic displacement has been applied to the top of the column in this cyclic loading. In the first and second stages, when the column is under axial stress, the columns are subjected to axial loading; they are then exposed to cyclic loading until the column is damaged, as illustrated in Figure 4.

The cross-section axial capacity (Nc) were adopted. The EN 1998-1 limits the design axial load to no more than 30% of the design column resistance for all composite columns in moment-resisting frames [9]. In this paper, the axial bearing capacity of the circular CFST columns can be calculated according to the ACI design code as expressed by Eq.1, where As and Ac are cross-sectional areas of the steel tube and the concrete core, respectively, fy and fc' are the yield strength of the steel tube and the concrete compressive cylinder strength, respectively [16].

$$N_{c,ACI} = A_s f_y + 0.85 A_c f_c' \tag{1}$$

Seamless pipes were employed in the steel walls of the columns. The steel walls have an inner diameter of 0.254 m and a thickness of 0.008 m, while the columns have a length of 2 meters. As a result, the diameter of outer steel wall is 0.27 m. Table 1 lists the other features of the tested columns, such as the steel mesh and concrete core properties. The interior steel mesh of the examined samples is also 0.227 m in diameter and near to the steel wall.

Figure 4: Experimental samples under axial and cyclic loading

Table 1: The Specifications of experimental samples

Sample name	Length (m)	Steel Wall Young's modulus (MPa)	f_y (MPa) Steel Wall	f_c' (MPa)
CFT	2.00	25614	337	32.4

Compressive strain, and Young's modulus about concrete for both CFT and UGCFT samples is respectively 0.00126 and 25614 MPa. According to the EN ISO 6892-1 standard, the yield strength of the steel wall and steel mesh is 337 and 326 MPa, respectively, and its elastic modulus is about 200000 MPa.

The ATC-24 code is used to apply cyclic loading to experimental samples and finite element models, as illustrated in Figure 5 [14].

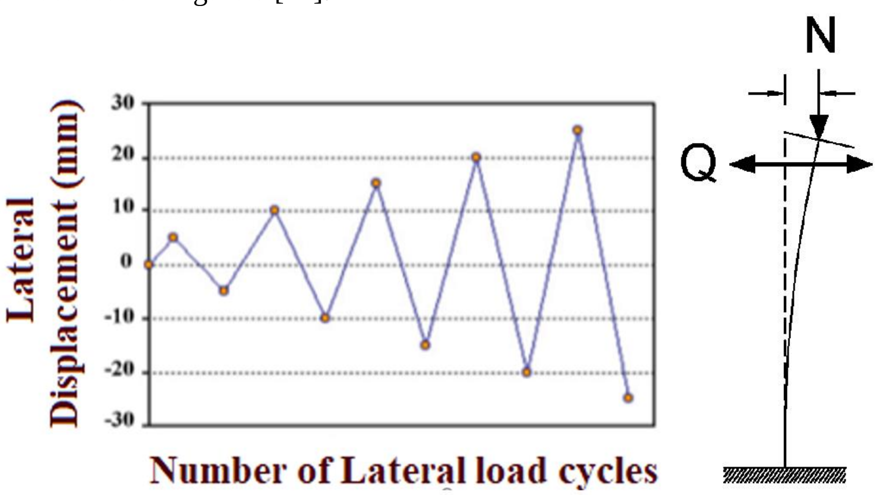

Figure 5. The cyclic loading history based on ATC-24 code

To model the numerical samples, first the inner concrete core is modeled by Solid65 element. In the next step, the external steel wall is modeled by Solid45 element. The essential thing is that the meshing of these parts is done in such a way that the nodes are coincided. Finally, all the nodes are merged.

The cross section of column modeled by Ansys software is shown in Figure 6. Figure 7 shows the modeled samples of experimental columns. All the nodes of the external steel wall located at 0.20 m from the base plate column have been fixed.

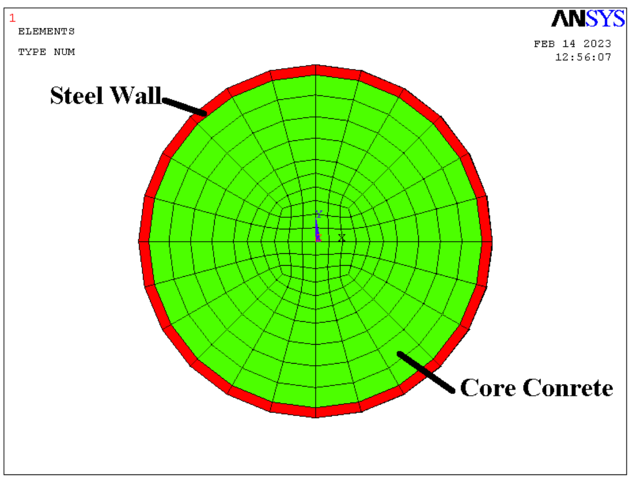

Figure 6. The modeling scheme of column samples in ANSYS

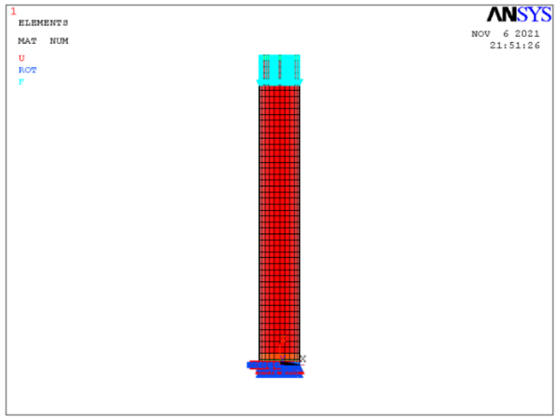

Figure 7. Modeling of experimental samples in ANSYS

The characteristics of the comparative samples modeled with different crushed stiffness factor are presented in the Table 2.

Table 2: The characteristics of concrete-filled steel column samples under investigating.

Row	**Sample name**	**f'_c (MPa) for core concrete**	**f_y (MPa) Steel Wall**	**Crushed Stiffness Factor (CSTIF)**
1	CSTIF=E-5	32.4	337	0.00001
2	CSTIF=E-4	32.4	337	0.0001
3	CSTIF=E-3	32.4	337	0.001
4	CSTIF=E-2	32.4	337	0.01
5	CSTIF=0.1	32.4	337	0.1
6	CSTIF=0.5	32.4	337	0.5
7	EXP	32.4	337	experimental

The hysteretic loops for experimental and numerical samples listed in Table 2 modeled in ANSYS under the same situation are compared in Figures 8 and 13. A gauge that it set up on the top level of the column measured the lateral displacement in the test. It seems that the steel mesh has maintained its performance until the end of loading in the laboratory. Loading continues until the column undergoes large deformations and collapses.

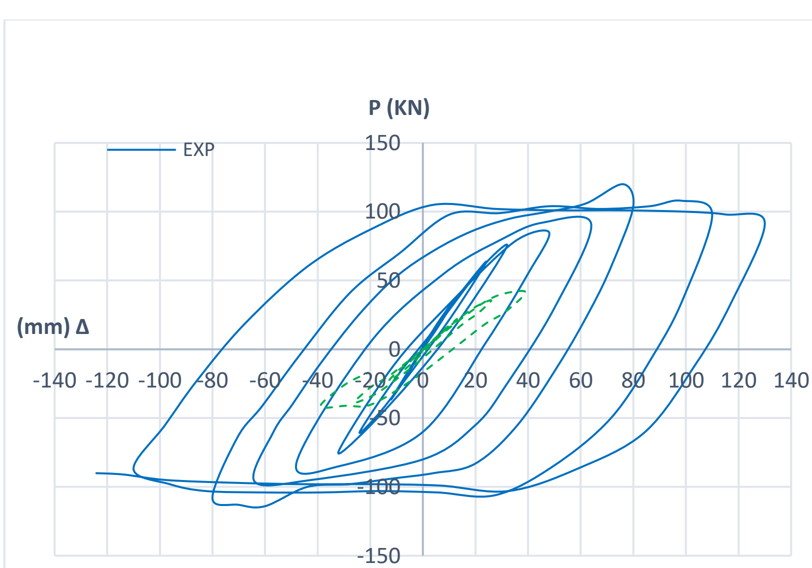

Figure 8. The lateral load- lateral displacement responses of CSTIF=E-5 and experimental sample

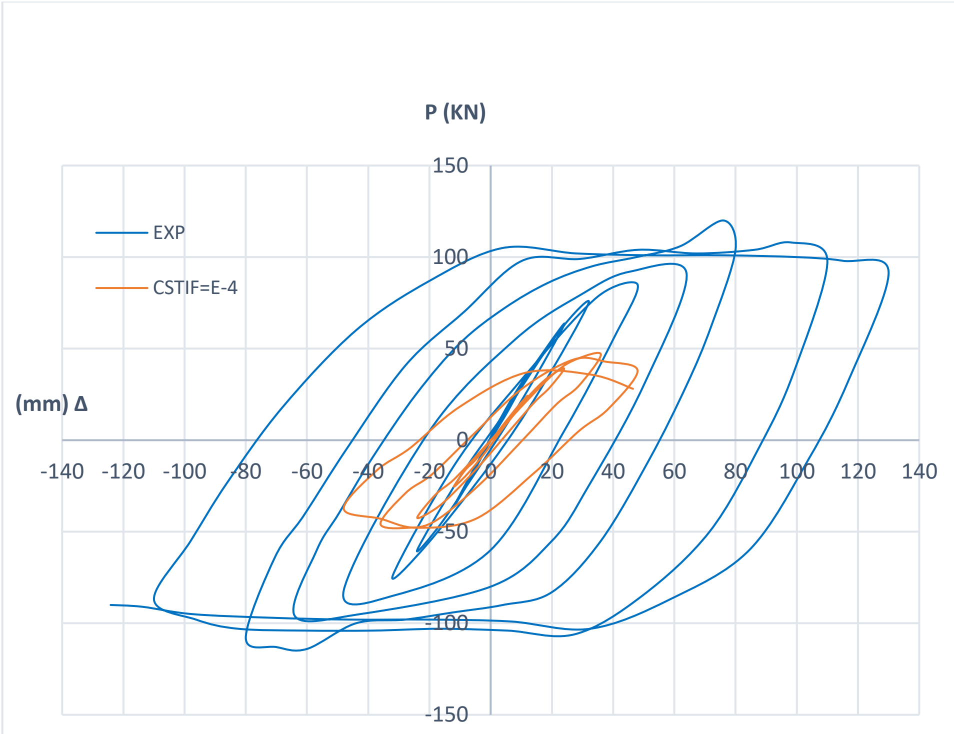

Figure 9. The lateral load- lateral displacement responses of CSTIF=E-4 and experimental sample

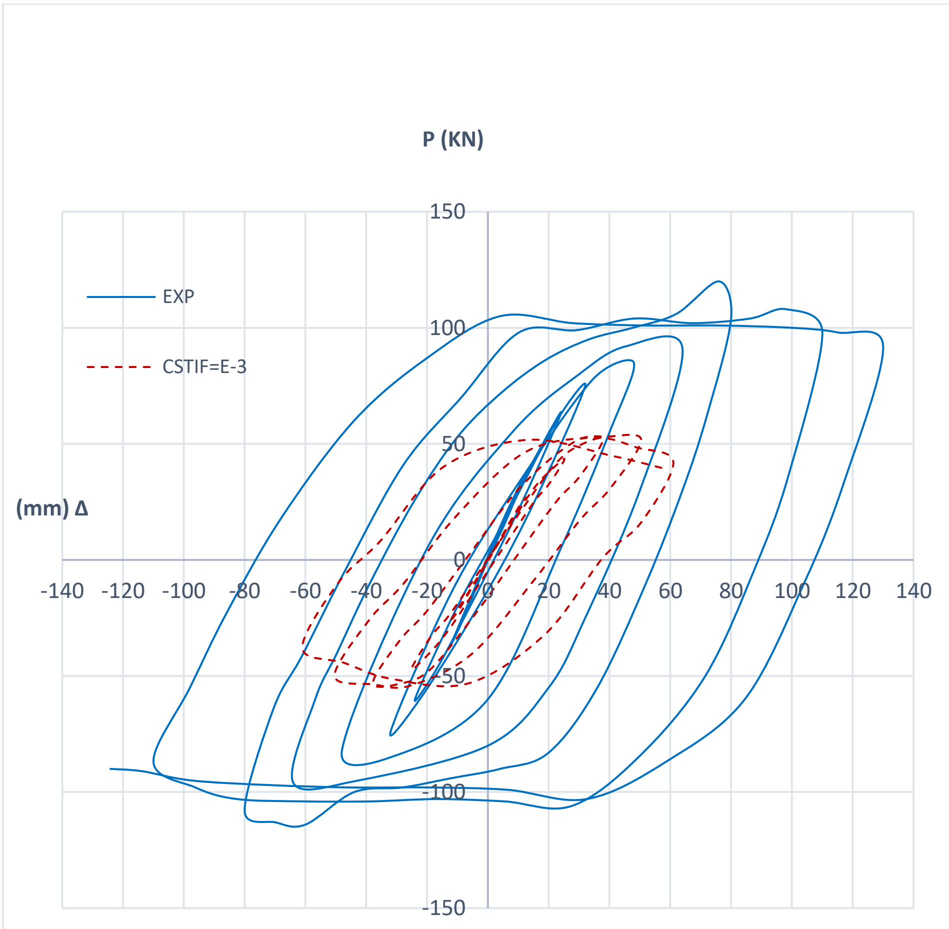

Figure 10. The lateral load- lateral displacement responses of CSTIF=E-3 and experimental sample

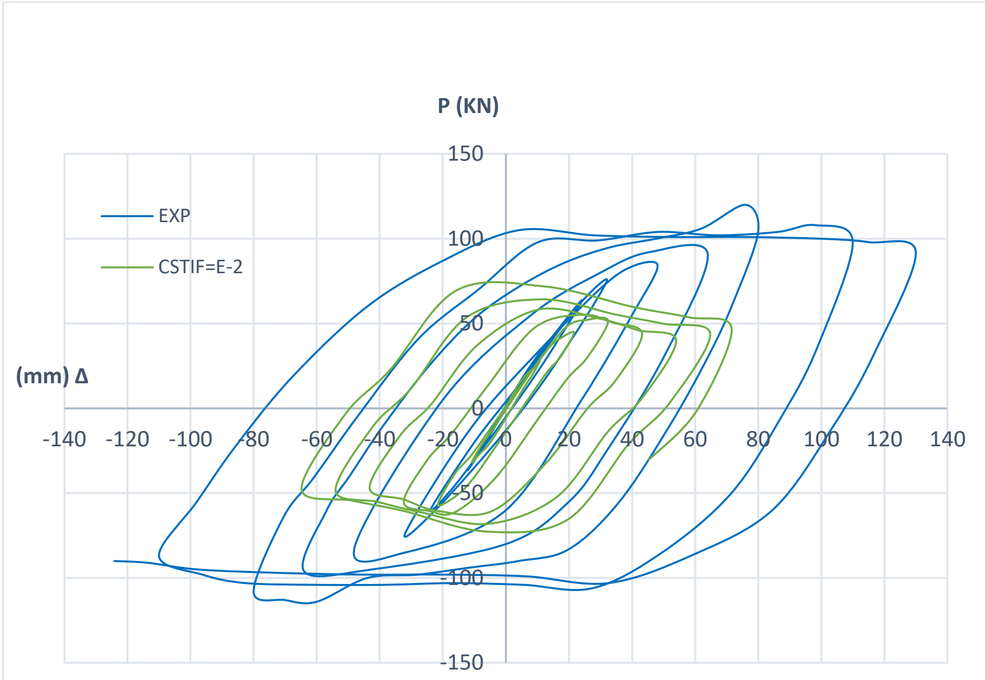

Figure 11. The lateral load- lateral displacement responses of CSTIF=E-2 and experimental sample

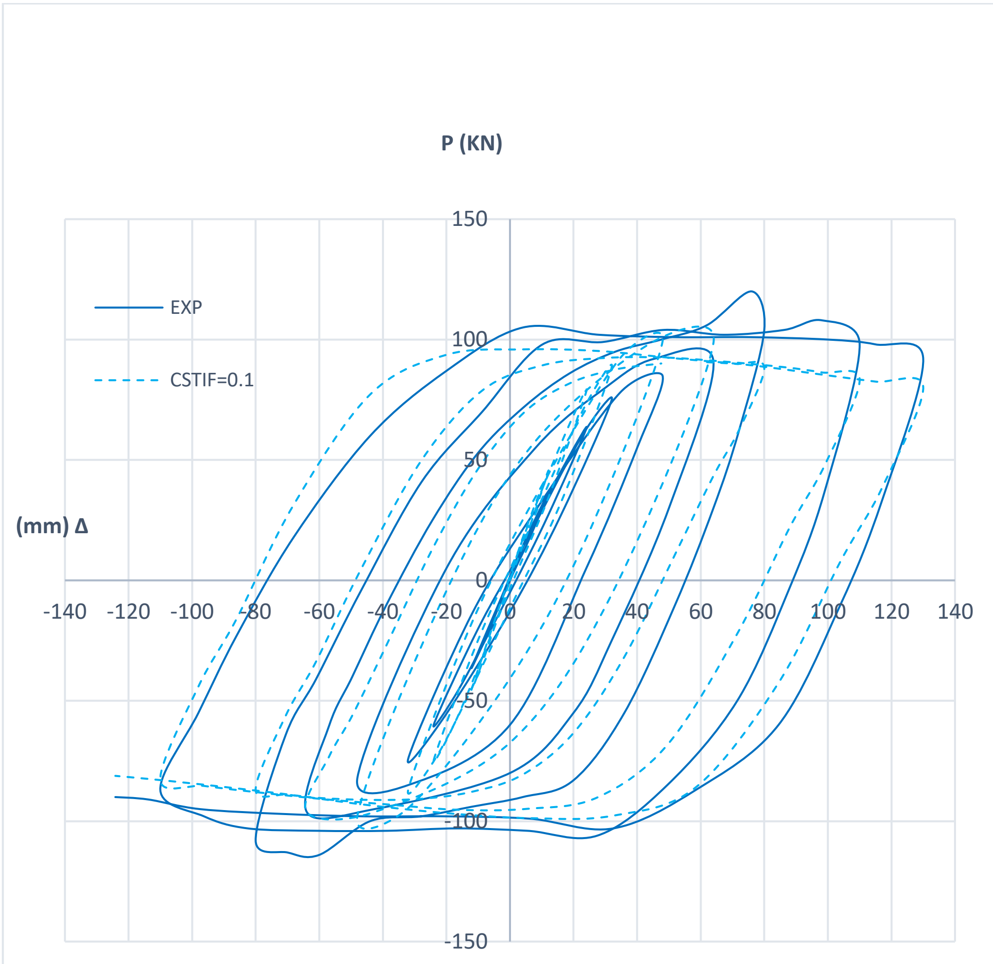

Figure 12. The lateral load- lateral displacement responses of CSTIF=E-2 and experimental sample

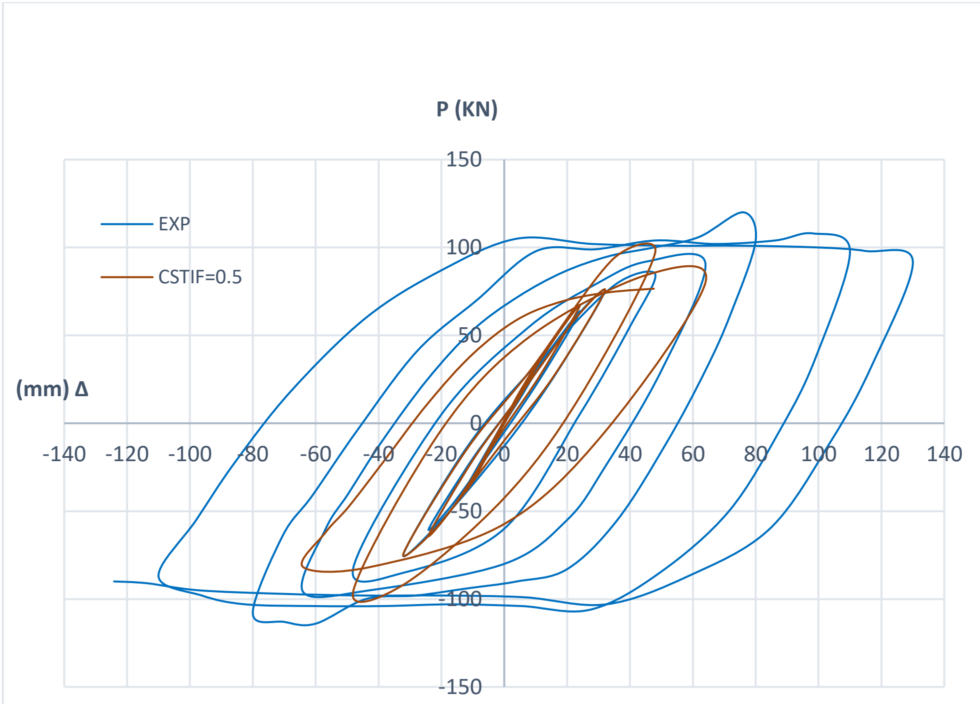

Figure 13. The lateral load- lateral displacement responses of CSTIF=E-2 and experimental sample

The envelope curves for experimental and numerical samples listed in Table 2 modeled in ANSYS under the same situation are compared in Figures 14.

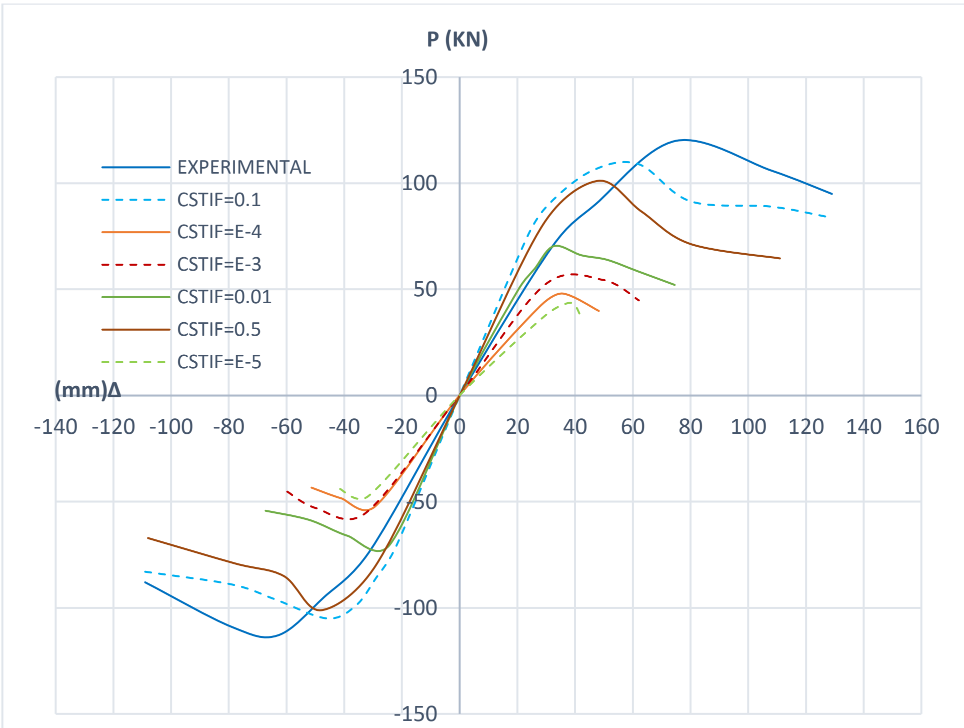

Figure 14. The envelope curves experimental samples and numerical models under axial and cyclic loading

According to the graphs shown and the obtained results, it can be concluded that in the concrete-filled steel column as a case study, with selecting Crushed Stiffness Factor (CSTIF) is equal to 0.1 the modeling results are close to each other.

CONCLUSIONS

It can be concluded that in the investigated column as a case study, the Crushed Stiffness Factor plays a significant role in matching the laboratory results with the numerical modeling results. Due to the confinement of the concrete by the external steel wall, the value of Crushed Stiffness Factor is equal to 0.1 for the concrete-filled steel columns, and it is expected that the value of this Factor may differ according to the conditions of the problem.

(Received February 2023, accepted February 2023)

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