Numerical Evaluation of Concrete Filled Steel Box Composite Column

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ABSTRACT

This study investigates the axial load behavior of concrete-filled fabricated steel box composite (CFSSBC) columns through a detailed parametric analysis. The primary objective is to evaluate how geometric and material parameters such as plate thickness (B/t), length-to-width ratio (L/B), and the compressive strengths of steel and concrete influence the structural performance of CFSSBC columns. A total of sixteen column specimens with varying geometric configurations were analyzed. Finite element analysis (FEA) was conducted using ANSYS software to simulate axial loading conditions, with material properties viz. modulus of elasticity and poison's ratio defined as 200GPa and 0.3 for steel, and $3750\sqrt{f'c}$ and 0.2 for concrete. Results revealed that increased confinement from steel plates significantly improves axial load capacity. The numerical results aligned closely with analytical predictions, confirming the accuracy of the simulation model. Furthermore, comparisons with design standards revealed that the AISC code offers more conservative estimates. This research provides valuable insights for optimizing CFSSBC column design in structural engineering applications.

1. INTRODUCTION

In recent decades, concrete-filled steel box composite columns have emerged as an essential component in structural engineering due to their superior strength, ductility, and energy dissipation capabilities. Among them, concrete-filled fabricated steel box composite (CFSSBC) columns are particularly promising, combining cast-in-place concrete with prefabricated steel box sections to form a highly efficient structural member. These columns eliminate the need for formwork, reduce construction time, and offer significant improvements in load-carrying capacity and stiffness. They are widely used in the construction of bridges, high-rise buildings, industrial structures, and infrastructures subjected to heavy axial and seismic loads. While CFST (Concrete-Filled Steel Tube) columns have been extensively researched, especially circular and rectangular hollow sections, the fabricated square steel box configuration remains underexplored, particularly with non-conventional materials such as brick aggregate concrete. Most existing studies have concentrated on standardized steel profiles and high-quality concrete mixes, without sufficient investigation into regionally available materials and fabrication-based steel geometries, which are often used in developing countries to reduce construction costs.

Moreover, key geometric parameters, such as the plate width-to-thickness ratio (B/t) and column slenderness ratio (L/B), are known to have a significant influence on both confinement behavior and buckling resistance. However, the combined effect of these parameters on the ultimate axial strength and ductility of CFSSBC columns has not been systematically addressed. In addition, design codes like AISC, ACI, and Eurocode 4 (EC4) provide general design formulations for composite columns, but their accuracy and conservativeness in predicting the axial capacity of fabricated square steel box columns filled with concrete remain questionable.

These research gaps suggest a need for a comprehensive and comparative study focusing on the parametric behavior of CFSSBC columns under axial loading. Understanding how varying the material properties of steel and concrete, along with geometric ratios, impacts the axial capacity and confinement efficiency is critical for advancing design practices and validating or modifying existing code provisions. Fig. 1 shows that the cross section of the composite column.

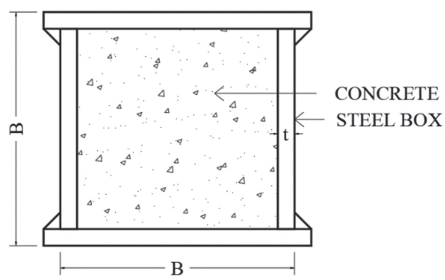

Fig. 1: Concrete Filled Steel Box Section Column

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This study aims to **investigate the axial compressive behavior** of CFSSBC columns through a combination of **numerical modeling and parametric analysis**. A total of 16 (sixteen) square column specimens were considered with varying:

- Plate thickness (B/t);
- Slenderness ratio (L/B);
- Concrete compressive strength;
- Steel yield strength.

Finite element analysis (FEA) was used to simulate the axial loading behavior and to evaluate the confinement effect provided by the fabricated steel box. The study also compares the results with the analytical predictions based on current design codes to assess their level of conservativeness and applicability.

Through this research, **new insights** are provided for:

- Enhancing the axial load design of CFSSBC columns;
- Understanding the confinement mechanisms in fabricated box systems;
- Assessing the suitability of international codes for non-standard columns.

Ultimately, this work aims to contribute toward more efficient and economical composite column designs, particularly in regions where custom-fabricated steel boxes and local aggregate concrete are commonly used.

A numerical investigation using finite element analysis (FEA) of concrete-filled steel box columns was performed. The materials used for the steel plate's strength are Q345, and the compressive strength of the concrete is 46MPa. ANSYS FEA software was used to conduct the finite element (FE) model, employing SOLID45 and SOLID65 elements to represent steel and concrete materials. The cracked and crashed concrete structure was checked using the William-Warnke five parameters rule. The finite element results shows that both the strength increasing coefficient of restrained concrete and the bearing capacity increasing coefficient decrease as the width-to-thickness ratio increases [1]. It was studied numerically using a steel yield strength of 235MPa and a concrete compressive strength of 62.3MPa on a double-skinned composite tube shaft that was put under an axial compressive load [2].

A study was conducted on square CFST columns subjected to concentric loading, using different grades of concrete and varying lengths to width ratios. ANSYS FEM software was used for numerical analysis, and the results show a good match with EC4 (1994) [3]. The behavior of high-strength steel box columns under axial compression is examined using steel plate materials with a strength of 460 MPa. Maximum column strength is affected by initial geometric imperfections and residual stresses [4]. ANSYS finite element analysis software was used to do a numerical study of the cycle behavior of eccentrically compressed steel box columns that were loaded cyclic horizontal loading, [5]. An experimental and numerical investigation on the concrete-filled stainless-steel column exposed to fire. The compressive strength of concrete used 41MPa to 46MPa and the maximum temperature used 800°C. The ABAQUS finite element software was used to conduct the thermal-stress analysis [6].

The eight-node SOLID45 element was used to model steel materials in the 3D numerical model, and the SOLID65 element was used to model concrete materials. The TARGE170 and CONTA173 elements were used to model how steel and concrete interact with each other. In conclusion the finite element model predicts the axial capacity of the columns [7]. A parametric study was conducted on CFST column with the use of different strength steel and concrete using constant height of 400mm with 150mm diameter specimen. The findings were a significant increase of the ultimate capacity of the CFST column by a smaller D/t ratio [8, 9].

A numerical study was done using square concrete-filled double steel tube short columns that were loaded eccentrically. The yield strength of the steel was 345MPa to 412MPa, and the compressive strength of the concrete was 19MPa to 20MPa. [10-12]. A nonlinear numerical analysis was done, and an equation was suggested for the axial loading capacity of a concrete filled steel tube column with initial imperfection [13]. An experimental, parametric and numerical study conclude the capacity due to various L/D ratios of 3, 4, 5 and 6. Local buckling mode of failure observed in all the specimen. ANSYS v18 finite element software was used to model the steel tube columns. A parametric study was conducted to verify the numerical results and the finite element modeling show the efficient comparison with the experimental results [14].

2. PARAMETRIC STUDY

Before conducting the parametric investigation, the finite element (FE) model was validated against experimental data to ensure its accuracy in simulating the axial behavior of concrete-filled fabricated steel box composite (CFSSBC) columns. The comparison focused on ultimate axial load capacity, load–displacement behavior, and failure modes. The results from the FE model closely matched the experimental observations, demonstrating the model's reliability. This validation establishes confidence in using the FE model for further parametric exploration. Fig. 2 shows the cross section of parametric column specimen.

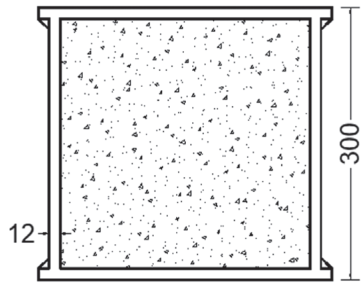

Fig. 2: Cross-section of Parametric Column Specimen

The aim of the parametric study is to systematically investigate how critical design variables influence the axial load behavior of CFSSBC columns. Parameters such as plate thickness (B/t), slenderness ratio (L/B), concrete compressive strength (f'c), and steel yield strength (fy) of sixteen column specimen as shown in Table I, have significant effects on the structural performance of composite columns. Through numerical modeling, the study evaluates how variations in these parameters affect the column's confinement efficiency, load capacity, and buckling behavior. The results also help assess the applicability and conservativeness of existing design standards (e.g., AISC, EC4). The CFSSBC columns were modeled using ANSYS Workbench with the following material properties and modeling techniques:

- **Steel:** Modeled using the 8-node SOLID185 element with bilinear isotropic hardening. The modulus of elasticity was set to 200GPa, and Poisson's ratio was 0.3. Four different yield strengths were used: 250MPa, 345MPa, 415MPa, and 500MPa;
- **Concrete:** Modeled with the SOLID65 element to simulate nonlinear behavior, including the Drucker Prager Damage Plasticity model. The modulus of elasticity was estimated using Ec as 3750√fc′, and Poisson's ratio was 0.2. Concrete compressive strengths varied from 21MPa to 41MPa;
- **Interaction:** The steel–concrete interface was modeled using surface-to-surface contact with friction to allow for load transfer while capturing interface slip effects. TARGE170 and CONTA173 elements were used to define the contact behavior.

A total of sixteen CFSSBC columns were modeled and grouped into four parametric sets to investigate the effects of different variables:

- **Group G1 (B/t variation):** Explored the influence of plate thickness (6mm, 8mm, 10mm, 12mm), affecting B/t ratios from 50 to 25, while keeping other parameters constant;
- **Group G2 (L/B variation):** Examined the influence of slenderness by varying column lengths (3 m to 6 m), corresponding to L/B ratios of 10 to 20, with constant plate thickness;
- **Group G3 (Concrete strength variation):** Investigated the impact of different concrete compressive strengths (21MPa to 41MPa) on axial capacity;
- **Group G4 (Steel strength variation):** Analyzed the effect of varying steel yield strength (250MPa to 500MPa) on load behavior and confinement.

Table I: Geometric and Materials Parameters of Specimens

SL	SP ID	B (mm)	t (mm)	L (mm)	B/t	L/B	f'c (MPa)	fy (MPa)
1	G106	300	6	3000	50	10	21	250
2	G108	300	8	3000	38	10	21	250
3	G110	300	10	3000	30	10	21	250
4	G112	300	12	3000	25	10	21	250
5	G212L3	300	12	3000	25	10	21	250
6	G212L4	300	12	4000	25	13	21	250
7	G212L5	300	12	5000	25	17	21	250
8	G212L6	300	12	6000	25	20	21	250
9	G312C21	300	12	3000	25	10	21	250
10	G312C28	300	12	3000	25	10	28	250
11	G312C35	300	12	3000	25	10	35	250
12	G312C41	300	12	3000	25	10	41	250
13	G412S250	300	12	3000	25	10	21	250
14	G412S345	300	12	3000	25	10	21	345
15	G412S415	300	12	3000	25	10	21	415
16	G412S500	300	12	3000	25	10	21	500

All models were simulated in ANSYS using displacement-controlled loading under axial compression. Boundary conditions were applied such that:

- One end was fully fixed to prevent displacement and rotation;
- The other end was free in rotation and horizontally restrained, but loaded axially downward.

A nonlinear buckling analysis was also conducted to determine the critical buckling load and to observe post-peak behavior. Numerical results were later compared with analytical predictions to assess the influence of parameters and evaluate code predictions.

2.1 Codes and Standards

Concrete-filled fabricated steel box composite (CFSSBC) columns are governed by several international design standards that provide guidelines for calculating their structural strength and behavior. Among them, the most commonly referenced are:

- **ACI 318-14** Building Code Requirements for Structural Concrete (American Concrete Institute);
- **AISC 360-16** Specification for Structural Steel Buildings (American Institute of Steel Construction);
- **Eurocode 4 (EN 1994-1-1:2004)** – Design of Composite Steel and Concrete Structures (European Committee for Standardization).

These standards outline methods to predict the axial load-bearing capacity of composite columns based on the material properties of concrete and steel, geometric dimensions, and structural interaction. They are widely used in practice due to their reliability and code-based safety factors.

In this study, the results from the finite element analysis (FEA) were compared with predictions derived from AISC 360-16 and Eurocode 4 to assess the conservativeness and applicability of each design approach for CFSSBC columns.

The AISC 360-16 "Specification for Structural Steel Buildings" from the American Institute of Steel Construction (AISC) has the design formulae for steel box composite columns that are filled with concrete. The following equation can be used to find the theoretical axial strength of a steel box composite column filled with concrete:

$$P_n = P_{n0}\left[0.685^{\left(\frac{P_{n0}}{P_e}\right)}\right] \quad (1)$$

$$P_{n0} = \left[A_s f_y + A_{sr}\, f_{ysr} + 0.85\, f_{cu} A_c\right] \quad (2)$$

$$P_e = \pi^2 EI_{eff}/KL^2 \quad (3)$$

$$P_u = A_s f_y + A_c\, f'_c \quad (4)$$

where,

Ac	=	area of concrete mm2;
Asr	=	area of continuous reinforcing bars, mm2;
As	=	area of steel section, mm2;
EIeff	=	effective moment of inertia rigidity of composite section, Kip-mm2;
fcu	=	specified minimum concrete compressive strength, MPa;
fy	=	yield stress of steel section, MPa;
fysr	=	specific minimum yield stress of reinforcing bars, MPa;
K	=	effective length factor;
L	=	laterally unbraced length of the member, mm.

2.2 Uses of Steel Plate

The used adjustable column was 300mm x 300mm, which made a total gross area of 90,000mm^2. Because plates are not all the same width, the areas for steel and concrete are not all the same. The estimated steel area for a 6mm plate is 3,564mm^2, which is 3.96% of the gross area. This is the smallest amount of steel used in the parametric columns. For example, when the plate is 12 mm thick, the steel percentage goes up to 7.84%, which is the highest in this study. These percentages are higher than the minimum standards set by the codes, which say that steel must make up at least 1% of the gross area.

2.3 Concrete Parameters

As part of the parametric study, brick aggregate concrete was used to figure out the factors for the concrete. According to the Bangladesh National Building Code (BNBC 2020), the modulus of elasticity for this concrete can be found using the equation 3750√f'c. The limits for strength ranged from 21Mpa to 41Mpa, and the poison ratio was set at 0.2. For the numerical study, all parametric columns were simulated with the same set of parameters.

3. RESULTS FROM NUMERICAL ANALYSIS

3.1 Effect of B/t Ratio

Although design codes provide general limits for B/t ratios, they do not fully address the nonlinear confinement effects that arise in composite columns with fabricated box sections. Therefore, a detailed parametric study was carried out to evaluate how plate thickness influences axial load capacity beyond simplified code assumptions. The ratio of width to thickness, B/t, is based on the width of the CFFSBC columns and the thickness of the walls or plates used to make the box section. Four different plate thicknesses are used so that the ratios of width to thickness (B/t) stay between 25 and 50. Other factors stay the same, such as the L/B ratio and the strengths of the concrete and steel. As shown in Table II, the B/t ratios were used in four parametric columns in Group G1. Table II also shows the analytical capacity of different methods and the numerical capacity of ANSYS software.

The ultimate capacity of the specimen is calculated from equation 5, the results are defined by $P_{n,EC4}$. The effect of B/t ratio on the ultimate capacity of the column is explored in the axial capacity increased as shown in Table II. When the B/t ratio is changed from 50 to 25, the CFFSBC column's maximum vertical capacity goes up by 48%. The $P_{num}/P_{n,EC4}$ ratio shows that the numerical simulation result is well matched with the ultimate capacity of all the specimen from Code provided equation. The load-displacement curve is made from the numerical results for the different plate thicknesses shown in Fig. 3. From Table II, it is observed that the column's axial strength goes down as the B/t ratio goes up. The smaller B/t ratio seen when thicker plates are used, which increases the amount of steel in the column and makes it stronger along its length. The analytical capacity of the column is calculated form the equation:

$$P_{n,Ec4} = A_c f_c + A_s f_y + A_{sr} f_{yr} \tag{5}$$

Raghabendra and Chen [8] did a parametric study with 13 specimens that were all the same size: 400 mm in height and 150 mm wide. Plates of different thicknesses and strengths of steel and concrete were used. The load displacement curve from their work is shown in Fig. 4. The curve shows that the higher the capacity, the lower the D/t ratio. This was also seen in this study.

Table II: Load Carrying Capacity of Specimens Having Different B/t ratios

SL	SP ID	B (mm)	t (mm)	L (mm)	B/t	L/B	$P_{n,ACI}$ (kN)	$P_{n,AISC}$ (kN)	$P_{n,EC4}$ (kN)	P_{Num} (kN)	$P_{Num}/P_{n,EC4}$	Capacity increase
1	G106	300	6	3000	50	10	3299	3149	3560	3618	1.02	1.00
2	G108	300	8	3000	38	10	3872	3706	4126	4145	1.00	1.15
3	G110	300	10	3000	30	10	4449	4265	4696	4718	1.00	1.31
4	G112	300	12	3000	25	10	5032	4825	5272	5295	1.00	1.48

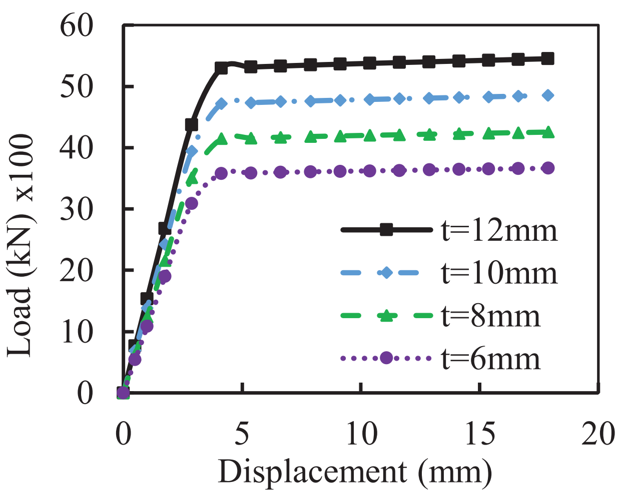

Fig. 3: Load Displacement Curve for Different Plate Thickness

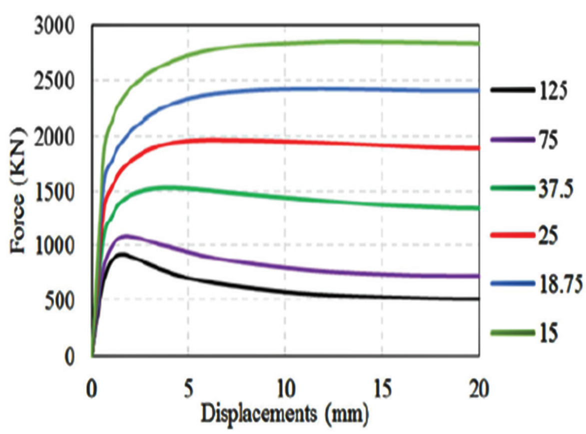

Fig. 4: Load Displacement for Different D/T Ratio [8]

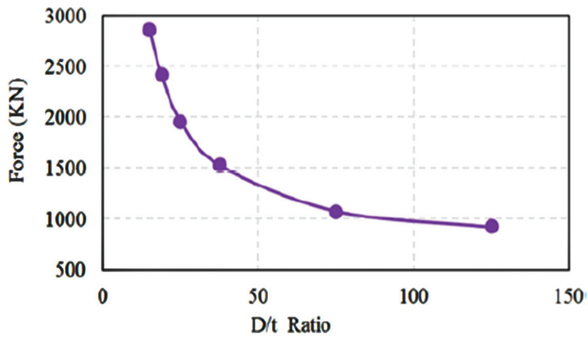

Fig. 5: Capacity Curve for Different B/t Ratios

In this study, Fig. 5 displays the axial strength capacity curve. The analytical capacity was found using the equation given by Eurocode EC 4. The ACI code equation capacity and the numerical capacity from the ANSYS FEM software were also looked into. The number result is very close to the value that the EC 4 code calculated. The capacity curve shows that the higher the B/t ratio, the smaller the capacity. This is also seen in the capacity curve of Raghavendra and Chen, which can be seen in Fig. 6. It is observed that while the numerical results closely match EC4 predictions, the enhanced confinement effect and localized buckling control due to thicker plates are not explicitly captured by the code equations. This highlights the need for such numerical studies to refine design understanding, especially for non-standard configurations.

3.2 Effect of L/B Ratio

Slenderness effects are often underrepresented in current design codes, especially for composite columns. This study examines how varying the L/B ratio affects load behavior, stability, and ductility using validated numerical models. The column specimen's length was varied from 3m to 6m to see how the column's axial strength changed. The L/B ratio factors change when the column length (L) changes. For each L/B ratio, ACI methods were used to figure out the column's axial strength. Fig. 7 displays the load-displacement curves of CFFSBC columns for group G2 that have various L/B ratios. The maximum capacity of the column doesn't change because the code doesn't include the effect of length in its formulas. But there is a change in the displacement; the highest sectional capacity stayed in the same line, but the displacement is changing. This shows that the column's ductility changes. In Table III, one can see the exact results for static analysis and the ACI code analytical results. It was seen that the numerical simulation results were a little higher than the ACI code analysis results. This is because the numerical simulation used the full strength of the materials. It was used a strength reduction factor in the ACI code to lower the strength.

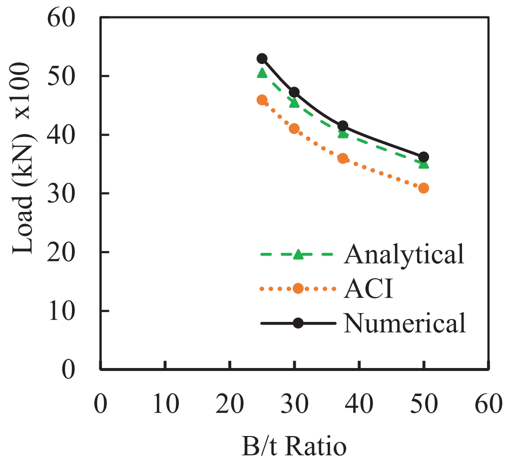

Fig. 6: Capacity Curve for Different D/t Ratios [8]

Table III: Capacity Different L/B (Static Analysis)

SP ID	L/B	$P_{n,ACI}$(kN)	P_{Num}(kN)	$P_{Num/}P_{Ana}$
G212L3	10	5272	5295	1.00
G212L4	13	5272	5293	1.00
G212L5	17	5272	5293	1.00
G212L6	20	5272	5290	1.00

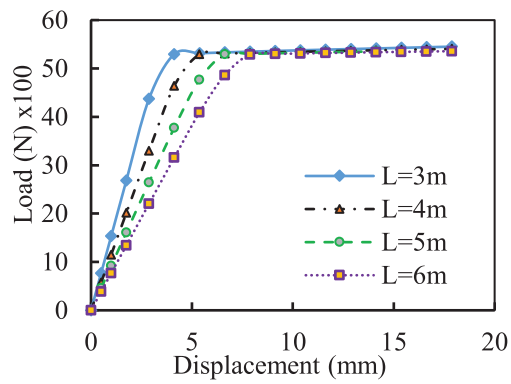

Fig. 7: Load Displacement Curve for Different L/B ratios

The ANSYS WORKBENCH also used the Eigen buckling analysis tool to do the buckling analysis. In group G2, the length of the columns was changed, but all other factors remained the same. The buckling analysis results with various L/B ratios are shown in Table IV. In Fig. 8, the relationship between load capacity and L/B ratios is displayed. The Eigen bending behavior of a numerical model is shown Fig. 9. In 2014, Bhushan and Mohite did a parametric study on a square CFST column with columns of different lengths. For numerical research, they use Euler's formula and the software ANSYS FEM. Fig. 10 displays the impact of changing L/B on the column's axial capacity, which is in line with this study.

Table IV: Capacity for Diff. L/B (Buckling Analysis)

SP ID	L/B	$P_{e,ACI}$(kN)	P_{Num}(kN)	P_{Num} /$P_{e,ACI}$
G212L3	10	52345	55605	1.06
G212L4	13	29444	31711	1.08
G212L5	17	18844	20720	1.10
G212L6	20	13072	14230	1.09

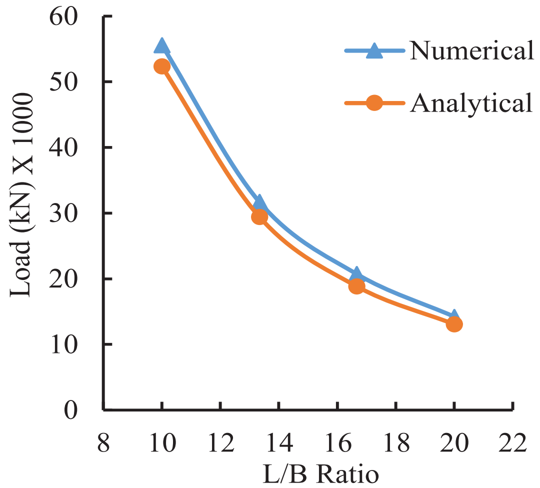

Fig. 8: Effect of L/B Ratio

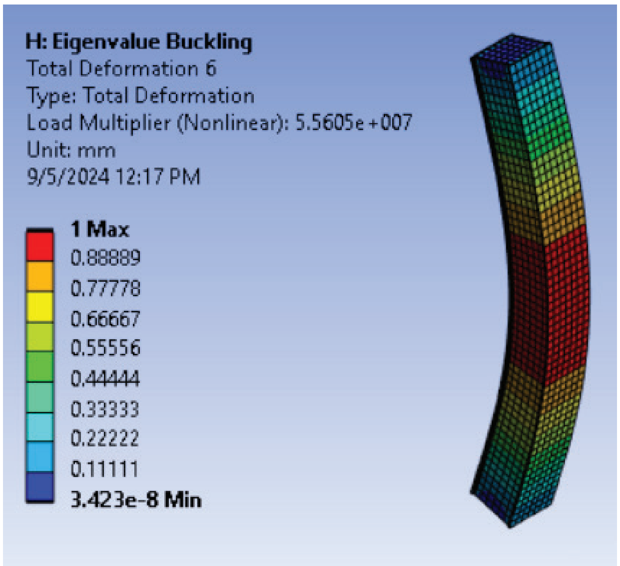

Fig. 9: Eigenvalue Buckling Plot

3.3 Effect of Concrete Strength

While codes assume linear improvements in strength with increasing f'_c, the interaction of high-strength concrete with steel plates in confined sections can exhibit nonlinear gains. Hence, a parametric analysis is essential to understand this behavior. The compressive strength of concrete is a key part of designing and studying composite columns. The compressive strength of concrete is one of the most important factors for the parametric study, and it also has a significant effect on how much load a column can withstand. For composite columns, the compressive strength of the concrete plays a vital role in determining the load-bearing capacity and stability of the column.

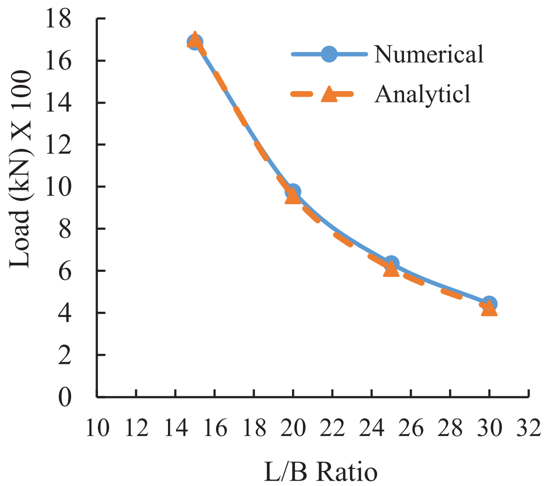

Fig. 10: Effect of L/B ratio (Bushan and Mohite)

Composite columns are made of both concrete and steel. They usually look like a steel section enclosed in concrete or a steel box filled with concrete (CFSB). By putting these two materials together, the column can benefit from both of their strengths: the crushing strength of concrete and the tensile strength and flexibility of steel. Table V shows the effect of changing the strength of concrete. It can be seen in Fig. 11 that the numerical load displacement curve for various f'_c is shown, and in Fig. 12, the capacity curve for various f'_c is shown.

Table V: Capacity of Different f'_c

SP ID	f'_c(MPa)	P_{Ana}(kN)	P_{Num}(kN)
G312C21	21	5272	5292
G312C28	28	5805	5810
G312C35	35	6338	6345
G312C41	41	6795	6814

3.4 Effect of Steel Strength

Design standards include basic provisions for steel yield strength, but do not capture how higher strength steel affects confinement, failure mode, or composite interaction. This study explores these effects numerically for a wide range of f_y values. A very important thing to think about when designing and evaluating composite columns is how strong the steel plates are. The steel's tensile strength is an important factor in parametric studies and has a significant effect on how much load composite columns can carry. The strength of the steel plate in a composite column denotes its capacity to endure compressive loads that aim to diminish its dimensions.

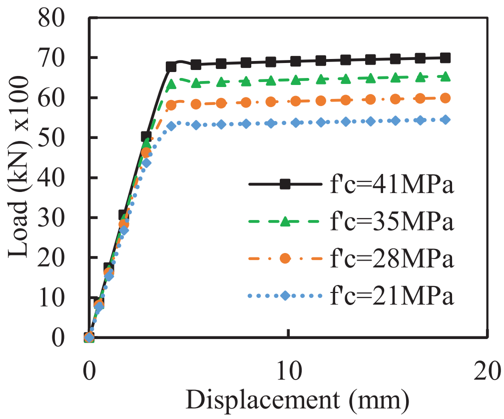

Fig. 11: Load Displacement Curve

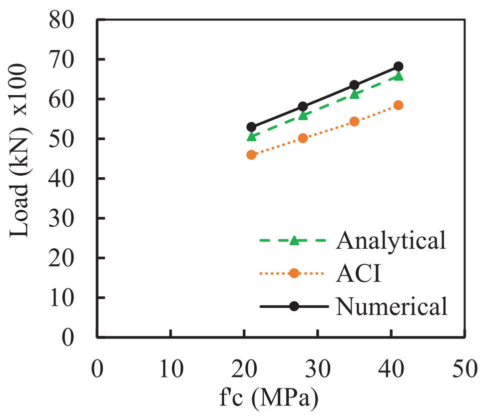

Fig. 12: Capacity Curve for Different $f'c$

Table VI: Capacity of Different f_y

SP ID	fy (MPa)	P_{Ana} (kN)	P_{Num} (kN)
G412S250	250	5272	5302
G412S345	345	6667	6708
G412S415	415	7695	7752
G412S500	500	8944	9013

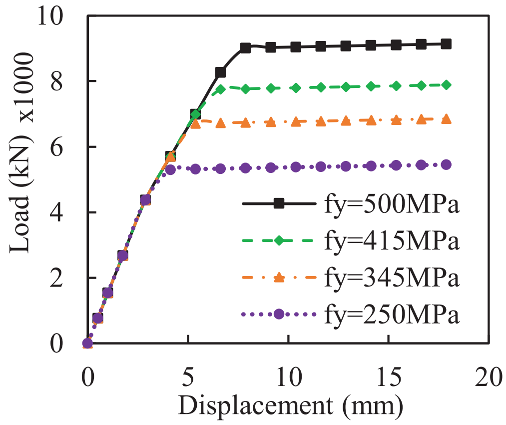

Fig. 13: Load Displacement Curve

The strength of steel plates is a vital consideration in the design and evaluation of composite columns. The tensile strength of the steel in composite columns is important for figuring out how much load they can carry and how stable they are. The results of the steel strength variance are shown in Table VI. Fig. 13 shows the numerical load-displacement curve, and Fig. 14 shows the capacity curve for steels of different strengths.

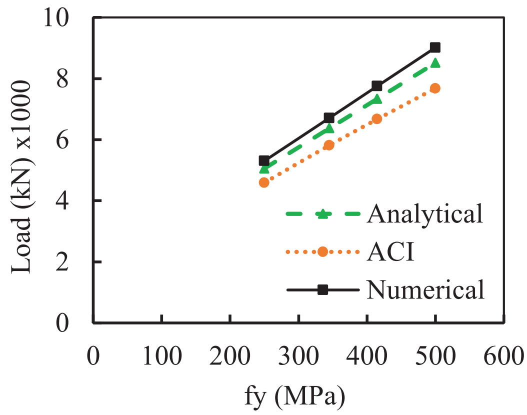

Fig. 14: Capacity Curve for Different f_y

4. CONCLUSION

In conclusion, the parametric study provides a comprehensive evaluation of how geometry and material characteristics influence the axial performance of CFSSBC columns. Although comparisons were made with existing design codes (ACI 318, AISC 360-16, and EC4), these standards have limitations in handling slenderness, local buckling, and high-strength materials. The finite element simulations, validated through experimental data, offer a more refined analysis of composite column behavior, supporting the need for future improvements in code formulations.

Here is a Summary of the Main Findings:

- When the axial capacities were estimated using various design codes, it was found that the AISC code is the most conservative of the bunch;
- Out of all the design codes, EC4 had the highest axial capacity, and the numerical results were very close to those of the EC4 code;
- The ACI code includes a strength reduction factor that makes the calculated capacities lower than the ultimate values. However, compared to the AISC code, they are slightly higher than the real capacities;
- The axial strength of CFFSBC columns increased as the B/t ratio dropped down because the thicker the steel plates made the columns stronger;
- Increasing the axial capacity of the columns happened when the L/B ratio decreasing;
- The numerical simulations closely matched the analytical results, and the variations observed were within acceptable limits.

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