SLENDERNESS (L/B) EFFECT ON THE AXIAL STRENGTH OF CONCRETE FILLED STEEL BOX COMPOSITE COLUMN

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ABSTRACT

The slenderness ratio (L/B) plays a crucial role in determining the structural behaviour and axial strength of concrete-filled steel box composite columns. This study investigates the influence of the slenderness ratio on the performance of such composite columns under axial loading. Six specimens were conducted on composite columns with varying slenderness ratios to assess their load-carrying capacity, deformation characteristics, and failure modes. Three hollow and three Concrete Filled Steel Box Composite (CFSBC) Column Specimen is tested under axial compressive load to observe the ultimate peak load, axial deformation, and failure pattern. The steel box section has been fabricated with A36 grade steel plates using welded joints in four corners. 3mm thick steel plate was use to prepare the steel box, the specimen length (L) was different in each specimen with same width (B) to observe the L/B effect on the peak load. Specimen size considers a compact section to observe the confinement effect and buckling effect. The load was applied through Universal Testing Machine and experimental data has been recorded in laptop using data logger. The results reveal significant insights into how the L/B ratio affects the behaviour of these composite columns. As the slenderness ratio increases, the column's axial strength tends to decrease, accompanied by changes in deformation patterns and failure mechanisms. The findings contribute a clear understanding of the structural response of concrete-filled steel box composite columns and provide valuable guidance for optimizing their design in practical engineering applications. This research underscores the importance of considering the slenderness ratio as a critical parameter when designing and evaluating the axial strength of concrete-filled steel box composite columns. By adapting the design to specific slenderness ratios, engineers can enhance the structural efficiency and reliability of such columns in various construction scenarios.

Key words: *Concrete, steel box, aggregate, plate thickness, slenderness, axial strength.*

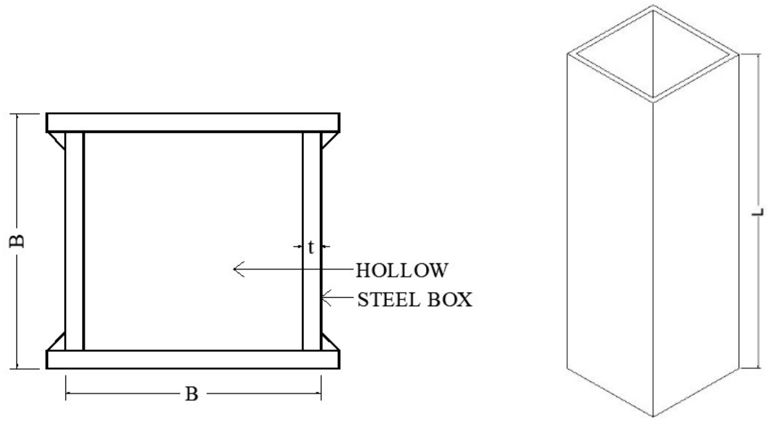
1. INTRODUCTION

Composite structures, combining the benefits of steel and concrete, have gained significant attention in structural engineering due to their enhanced performance and versatility. Among these composite elements, concrete-filled steel box columns stand out as a promising solution for high-rise buildings and bridges, where the demand for both strength and efficiency is critical. The slender nature of a column, characterized by its length-to-breadth ratio (L/B), plays an essential role in determining its structural behaviour and overall performance. Understanding the influence of slenderness on the axial strength of concrete-filled steel box composite columns is paramount for optimizing the design and ensuring structural integrity under various loading conditions. This research explores the relationship between slenderness and axial strength, aiming to understand the effects that varying L/B ratios have on the performance of these composite columns. By comprehensively exploring the interplay between geometry, material properties, and structural behaviour, this study contributes valuable insights to the ongoing efforts in advancing the design and construction of tall and slender structures. As the construction industry continues to push the boundaries of architectural design, the findings of this research will provide engineers and designers with essential knowledge to make informed decisions in creating safe, efficient, and resilient composite structures, addressing the challenges posed by different slenderness ratios in concrete-filled steel box columns.

The experimental, theoretical and numerical research were conducted on concrete filled steel box composite column from 1960 to till date by many researchers. Experimental study on the ultimate strengths of concrete filled steel concrete box columns with local buckling effects conducted by Ge and Usami (1992), Uy and Bradford (1995). Liang and Uy (2000) experiment on the effect of local bucking of concrete-filled steel box columns. Liang et al. (2006) studid on the behaviour of concrete filled thin wall steel box column with local buckling effect. He utilized the width to thickness ration (B/t) 49 so that local buckling can occurs. Goode et al. (2010) studied on concrete filled steel tubes experimentaly and observed the load bearing capacity of the members with selender section. Chen et al. (2012) studied on the local buckling and confinement effect of concrete filled box composite stub column experimentally as well as numerically. They described the confinement mechanism come from horizontal and vertical arch action of concrete. Mohammed et al. (2015) studied on recycled brick as aggregate. Long at el. (2016) study on the local buckling effect on the concrete filled rectangular column and the sutdy found that local buckling stress of steel plates in eccentrically loaded rectangular CFT column is signicantly influenced by the stress gradiant coefficients and width-thickness ratios while, it is slightly influenced by cross-sectional aspect rations. Na et al. (2018) study on slenderness effect of concrete filled tube with CFRP warpping and observed that the strengthening effect of the CFRP hoop warps decreased when the slenderness ratio increased. Yu et al. (2021) studied on the slender concrete filled wide rectangular steel tube (CFWRST) column experimentaly and numericaly. They also comparer the experimental results with Australian, Americal, European and Chinej code. He found that the chinej code conservatively predict the behavior of CFWRST column with in the devioation of 10% for most numerical results.

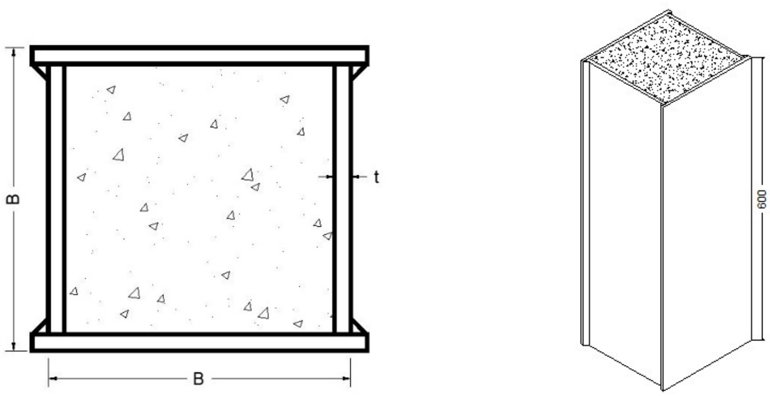
2. EXPERIMENTAL TEST PROGRAM

The test program consisted of three hollow steel box columns and three concrete-filled composite CFSBC columns with same sizes, different plate thicknesses with normal concrete strength. The column width 'B' had taken for this study was 75mm. Plate thickness was taken 3 mm, the width to thickness ratio kept 25. The steel box was square in size and fabricated in local work shop with the help of fillet welding at corners. The length (L) of the specimen had taken 750mm, 675mm and 600mm to round up the L/B ratio 10, 9 and 8 respectively. The title of hollow sections comes like 'HS-75-3-10' meaning the first number is the width of section 'B', the second number is the plate thickness 't' and third number is the L/B ratio. Other three specimen filled with concrete and named as a filled section marked with 'FVB-75-3-10', which means Filled section with Virgin Brick aggregate 75mm wide, 3mm thick and L/B is 10. The concrete strength f'c found 20.5MPa and Steel Strength found 250MPa from test results. Figure 1 and Figure 2 show the sectional view of the hollow and filled specimens.



(a) Cross Section (b) Isometric View

Figure 1: Hollow Specimen



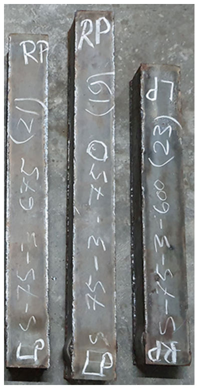
(a) Cross Section (b) Isometric View

Figure 2: Filled Specimen

The columns were tested for the concentric load to observe the failure peak load and axial deformation of CFSBC columns. The hollow box section and CFSBC column are shown in Figure 3. The geometric properties of the test column specimens are shown in Table 1.

Table 1 Geometric properties of test specimens

Sl. No.	Specimen ID	Size B (mm)	Thickness t (mm)	Length L (mm)	B/t Ratio	L/B Ratio
1	FVB-75-3-10	75	3	750	25.0	10
2	HS-75-3-10					
3	FVB-75-3-9	75	3	675	25.0	9
4	HS-75-3-9					
5	FVB-75-3-8	75	3	600	25.0	8
6	HS-75-3-8					



a) Hollow Specimen

b) Filled Specimen

Figure 3: Image of a) Hollow Specimen b) Filled Specimen

3. EXPERIMENTAL TEST SETUP

All the specimens are axially loaded by the Universal Testing Machine (UTM) with the load capacity of 2000kN at the Materials testing laboratory of Dhaka University of Engineering & Technology, Gazipur. The load was applied as a displacement from the bottom of the specimen. One linear variable displacement transducer (LVDT) was used to record the axial displacement of the specimen for the applied axial load which was installed vertically parallel with the specimen. Two LVDT were installed horizontally in the middle of the specimen to read the lateral displacement of the specimen. A 1000kN load cell was set at the bottom of the specimen to record the load data. A UCAM B60 data logger was used to record all the test data and finally the load and displacement data were read and stored in a laptop. Two end plates were used at both ends of the specimen for transferring the load uniformly. The UTM machine applied the load in terms of displacement. The load was applied up to the failure of the specimen. The schematic diagram and instrument setup are shown in Figure 4.

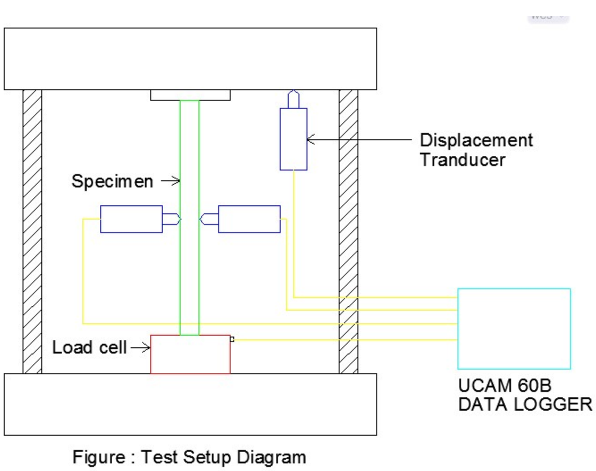


Figure 4: Schematic Diagram and Instrument Setup

4. MATERIAL PROPERTIES

The concrete filled fabricated steel box composite column had two section, Main section is the hollow steel section and other is infill concrete section. Different code had been describing the metallurgy of the steel material and as well as concrete materials. For the steel materials mild steel, alloy steel, low carbon and high carbon steel could be used to fabricate the steel box columns as per their requirements. ACI, AISC and EC4 had specific guide line for the strength of steel material use. Bangladesh National Building Code BNBC 2020 described a strength rage of steel plate materials in Part VI Chapter 13 steel concrete composite structural members.

4.1 Steel Materials Properties

ASTM A36 steel plate was used in this study, which was collected from our local market. 3mm thickness steel plate was used for fabricating the steel box column. Three steel plate coupon sample of 3mm thickness were considered for the tensile strength test and average yield strength *fy* was found 250MPa. As per ASTM standard the Fu assume 400MPa. The test was conducted in the materials testing laboratory of DUET with the help of Universal Testing Machine (UTM).

4.2. Concrete Materials Properties

Brick aggregate concrete was used in this study. The mix ratio was considered as 1:1½:3 for the preparation of concrete. The size of coarse aggregate was ¾ inch downgraded and the fineness modulus (FM) of sand (coarse sand) was found 2.50. Locally available King Brand cement was used in concrete. Representative concrete cylinders test was conducted and the average result found 20.5MPa.

5. TEST RESULT AND DISCUSSION

The load displacement relation of hollow and CFSBC column specimens are shown in Figure 5. The dotted line shows load displacement relation of hollow box specimen and the solid line shows the same of the concrete filled box composite column specimen. The vertical axis of the curve indicates the applied load data and the horizontal axis indicates the axial displacement data. The peak load of each specimen was found from the test result and it is denoted by P_{exp} and shown in Table 2. At the beginning of the applied load, the displacement for the first few points is higher and not linear with the applied load. As a result, a 'S' curve is formed at the starting of the load-displacement curve.

The American Institute of Steel Construction (AISC) provides the design equations for concrete-filled steel box composite columns in the AISC 360-16 "Specification for Structural Steel Buildings".The nominal axial strength of a concrete-filled steel box composite column can be determined using the following equation:

$$P_n = P_{no}\,[.658^{(Pno/Pe)}] \tag{1}$$

Where

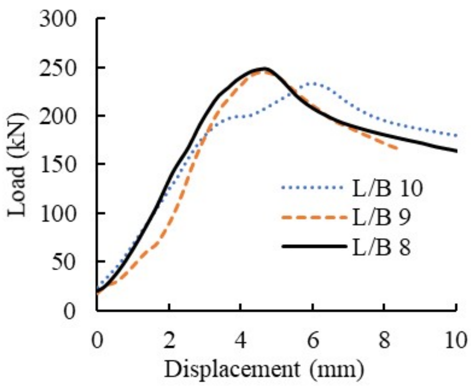
$P_{no} = [As\,fy + Asr\,fysr + 0.85fcu\,Ac\,]$ and $Pe = \pi^2(EI)_{\mathrm{eff}} / (KL)^2$

The steel box capacity was found from the hollow sections test results, while the composite sections results was found from the filled specimen resuts. The strength difference of the two resuts of hollow and filled specimens is due to the infill concrete strength capacity. Form the first two result, the failure strength of filled specimen FVB-75-3-10 found 330kN and 233kN strength found in hollow box specimen HS-75-3-10. The increased strength of the concrete filled specimen is 97kN. This additional capacity increase due to the in-filled concrete and steel concrete combine effect. The L/B ratio for this two specimens was 10. The failure strenght was found 357kN for third specimen FVB-75-3-9 and also found 364kN for the 5th filled specimen FVB-75-3-8. The L/B ratios were 9 and 8 for those filled specimens. The maximum axial strength observed 364kN, in which the L/B ratio was 8. The lower value of L/B ratio observed highter capacity. It has been also observed that for the hollow specimen HS-75-3-8, which have a lower value of L/B ratio found higher capacity of failure strength 248kN.

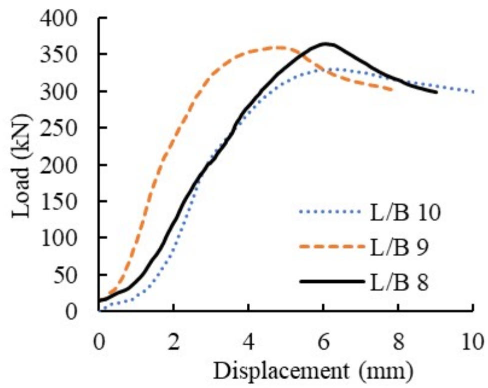
Figure 5 shows the load displacement relation of hollow and filled specimen. The experimental and numerical axial capacities along with their ratios of all the specimens are listed in Table 2.

Table 2: Experimental and analytical Results

SL No	Specimen ID	Concrete *f'c(Mpa)*	Steel *f'y(Mpa)*	Steel *f'u(Mpa)*	P_{exp}	P_{ana}	P_{ana}/P_{exp}
1	FVB-75-3-10	20.5	250	315	331.0	300.0	0.91
2	HS-75-3-10		250	315	233.0	221.0	0.94
3	FVB-75-3-9	20.5	250	315	357.0	302.0	0.84
4	HS-75-3-9		250	315	245.0	223.0	0.90
5	FVB-75-3-8	20.5	250	315	364.0	304.0	0.83
6	HS-75-3-8		250	315	248.0	224.0	0.90



(a)Hollow section



(b) Concrete filled section

Figure 5: Experimental Load Displacement Relations

6. NUMERICAL ANALYSIS AND MODELING

All the test specimens are modelled with a 3D finite element analysis software ANSYS Mechanical APDL (Ansys Parametric Design Language). The materials and geometric properties are model with built-in solid elements. Solid 65 element was used for concrete simulation and solid 185 element used for simulate the steel materials simulation. After completed the 3D model of the specimens, the model was meshed with required parameters and after that the boundary conditions were applied as per the experimental condition. The applied load was applied on the model specimens as per the laboratory load arrangement. Finally, the program solver was setting in linear and nonlinear mode, set all other related conditions and the solver solved the linear and nonlinear solutions. Figure 6 show the solid 65 element geometry. The numerical model of the hollow and concrete filled specimens are shown in Figure 7.

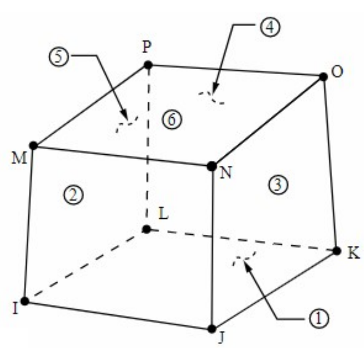
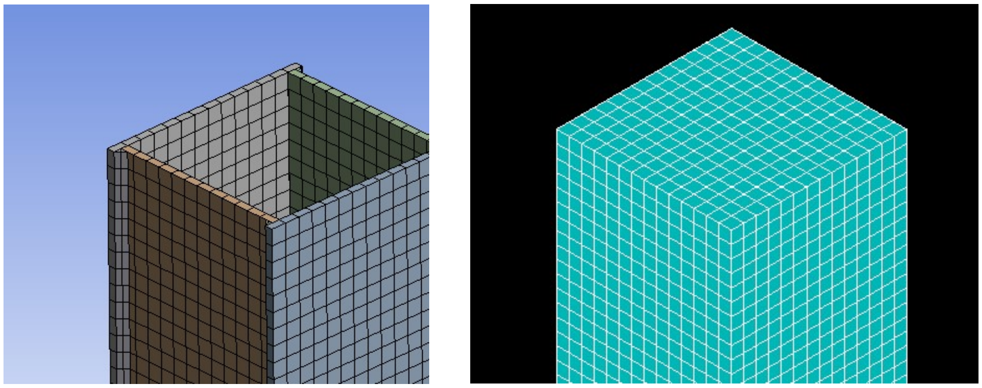


Figure 6: A Solid 65 Element



(a) Hollow column specimen (b) Filled column specimen

Figure 7: Numerical Model

6.1 Numerical analysis and failure mode

All the test specimen are modeled with ANSYS Mechanical APDL (Ansys Parametric Design Language), inputting all the same properties as the test specimen had been prepared. Setting up the program solver in linear and nonlinear setups and set all other related conditions, the solver solve the linear and nonlinear solutions. After completion the solution, the behavior of the the hollow steel columns and CFSBC columns have been observed recorded the required data for presentation in figure. From the simulation, the failure strengths of FVB-75-3-10, FVB-75-3-9, FVB-75-3-8 CFFSBC column specimens are found 341.0kN, 354.0kN and 370.0kN respectively. The failure strength found maximum of 370kN of the specimen having lower L/B ratio of 8. Numerical results are compared with the experimental results in Table 3.

Table 3 Numerical Results

SL No	Specimen ID	Concrete $f'c$(Mpa)	Steel $f'y$(Mpa)	Steel $f'u$(Mpa)	P_{exp}	P_{num}	P_{num}/P_{exp}
1	FVB-75-3-10	20.49	250	315	330.6	341.0	1.03
2	HS-75-3-10		250	315	233.4	266.1	1.14
3	FVB-75-3-9	20.49	250	315	357.0	353.9	0.99
4	HS-75-3-9		250	315	245.0	258.6	1.06
5	FVB-75-3-8	20.49	250	315	364.0	370.1	1.02
6	HS-75-3-8		250	315	248.0	262.7	1.06

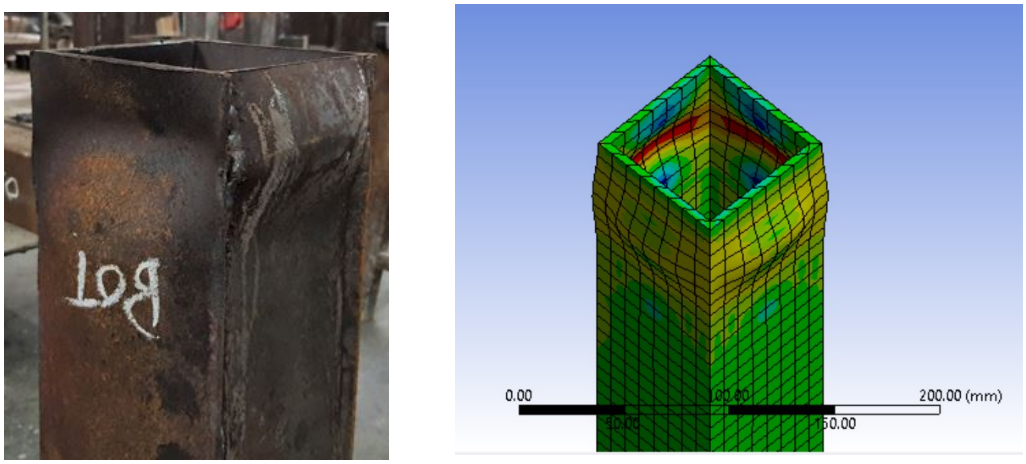
The failure patterns of the specimens during experiment and in numerical model also found similar behavior as shown in Figure 8.

7. CONCLUSIONS

The axial capacity of the concrete filled steel box composite column depends on different parameters and materials strength. In this study L/B parameter was the concern parameter for the column strength prediction with all other parameter considering same. The L/B ratio had been varied with the value of 8 to 10 and observed the hollow and filled specimen capacities.

a) The hollow specimen capacity increase less than 1% with the decrese of L/B ratio from 10 to 8.
b) The CFSBC column capacity increased 10% with decrese of the L/B ratio from 10 to 8.

c) The numerical simulation results resonable match with the experimenal results and the behavior of the failure modes simulate well aggred.



(a) Failure Pattern (Experiment) (b) Failure Pattern (Numerical)

Figure 8: Experimental and numerical failure behavior

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