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Experimental investigation on the confining effect of brick aggregate concrete in fabricated steel box composite column

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Abstract

Concrete filled fabricated steel box composite (CFFSBC) columns are widely used in building because of their strength, stiffness, and ductility. The elimination of formwork in these columns has significantly accelerated the construction process of tall, wide-span, and large-scale architectural projects. CFFSBC columns have been employed in the construction of tall buildings, bridge piers, and other extensive structures capable of withstanding seismic activity. CFFSBC columns have been used to make high-rise buildings, bridge piers, and other large constructions that can withstand earthquakes. The lack of availability of natural stone in South Asian subcontinent necessitates the use of crushed bricks as an alternate source of coarse aggregate to construct test columns to reflect a substantial practice adopted in the region. Prior studies have shown that the shrinkage, modulus of elasticity, and dilation characteristics of concrete produced using brick aggregate differ from those of concrete produced using stone aggregate. This study focuses on the analysis of CFFSBC columns constructed using crushed bricks. Five CFFSBC Columns were constructed using crushed bricks, contributing to the achievement of the aim. Then, these columns were put through axial compressive load tests, where their final peak load, axial deformation, and failure pattern were observed. In this study, boxes were fabricated by welding all four sides of a specific type of structural steel plate using the parameters of concrete strength, plate thickness, B/t ratio, and L/B ratio. An automatic data acquisition apparatus was utilized, incorporating a data logger and displacement transducers, to record the experimental data. The experimental findings were analysed to determine the deformation of the shape under axial stress and ascertain the impact of the confinement effect. Ultimately, the outcomes are evaluated by comparing the equations provided by the code with those found in the published literature.

Keywords: Composite columns, brick aggregate concrete, axial capacity, confinement effect.

1. Introduction

Concrete-filled steel box composite columns are widely employed in tall buildings, bridges, and various infrastructure projects due to their exceptional attributes-high strength, durability, adaptability, and versatility. This composite column configuration comprises a steel box filled with concrete, creating a structurally efficient element capable of withstanding significant axial and lateral loads. Extensive research over recent decades has explored into the performance of composite column under various loading conditions, particularly investigating their strength, stiffness, and ductility. The confinement effect, denoting the steel plate's ability to confine the concrete core and increase its axial strength, significantly influences composite column performance, especially under high axial loading. Applying confinement to these columns strengthen their load-bearing capacity and ductility, reduces buckling and collapse risks, and enhance their energy absorption capabilities. The effectiveness of this confinement in concrete-filled composite columns relies on the ratio of the steel plate's width to its thickness (Wright, 1995). However, despite the pivotal role of the confinement effect, knowledge gaps persist. Previous research has predominantly examined the behaviour of square or circular columns, with comparatively less emphasis given to alternate coarse aggregate of crushed stone. Furthermore, the comprehensive understanding of the impact of materials, including the specific kind of steel plates, the thickness of the concrete cover, and the level of confinement, on the structural response of composite columns remains un-investigated. In addition, it should be noted that the current design codes and standards related to composite columns lack a comprehensive methodology for incorporating the confinement effect. Moreover, several design equations in these codes rely on empirical correlations rather than solid theoretical foundations.

The experimental, theoretical and numerical researches on concrete filled steel hot rolled section and steel tube from 1960 to till date by many researchers. Furlong (1967) investigated on the ultimate loads of concrete-filled steel box columns. Furlong commented that the confinement effect of concrete does not affect the ultimate strength of the composite column and the steel and concrete contribute the strength independently. Knowles and Park (1969), Tomii et al., (1977), Shakir-Khalil and Mouli (1990) and Schneider (1998) studied on concrete-filled steel tubular column also. They commented that the concrete confinement was found in the concrete-filled circular and octagonal shape steel columns. They did not find confinement effect in square columns. Liang and Uy (1998) studied on the concrete filled thin-walled steel box columns. Wright (1995) observed that width to thickness ratio effect of steel plate in concrete filled column with the use of an energy method. Experimental study on the ultimate strength of concrete filled steel concrete box columns with local buckling effects of concrete-filled steel box columns conducted by Ge and Usami (1992). Uy and Bradford (1995) and Uy (2000). Liang (2006) studied on the behaviour of concrete filled thin wall steel box column with local buckling effect. He used the width to thickness ration (B/t) 49 so that local buckling can occurs. Chen (2012) studied on the local buckling and confinement effect of concrete filled box composite stub columns. Chen described the confinement mechanism observe from horizontal and vertical arch action of concrete. He explained the corner stress in welded box column become high and the failure of concrete start from corner. Mohammed et al., (2015) studied on recycling of brick aggregate concrete as coarse aggregate. Mohammed commented that, by recycling, it is possible to make concrete with more strength compared with the in-situ strength or concrete of old structure. Rahman et al., (2016) studied on the behaviour of partially encase composite column and he found that the axial capacity of the same increase significantly by increase the strength of concrete. Choudhury et al., (2016) studied on the CFRP and GFRP confinement of concrete under axial compression. Choudhury observed that the brick aggregate and recycled brick aggregate concrete exhibit greater dilation in axial compression.

Ming-Chang Wu (2018) investigated the potential size effect on axial behaviour of concrete filled box columns experimentally and numerically with ABAQUS. It was observed that the size effect was prominent for the concrete-filled box columns. Yuan et al., (2019) carried out a numerical simulation on the behaviour of square stiffened CFST stub columns under axial compression. CFST columns with large B/t ratios were susceptible to outward buckling upon axial compression. Chen et al., (2021) studied the mechanism analysis of concrete-filled square steel tubular columns reinforced by rhombic stirrups under axial compression. It is observed that the strength of the concrete-filled square steel tubular column increased by the use of rhombic stirrup cages.

2. Methodology

This experimental investigation aims to comprehensively analyze the confinement effect observed by brick aggregate concrete within fabricated steel box composite columns. The methodology employed for this study involves an exact procedure of material selection, sample preparation, experimental procedures, data collection, and subsequent analysis.

The primary objective is to study the behavior of these composite columns under axial compressive loading, thereby investigating the effectiveness of brick aggregate concrete in confining steel columns. The following sections detail the methodology implemented to conduct the experimental investigation, highlighting the procedures adopted for construction, testing, data collection, and subsequent analysis of the fabricated steel box composite columns. Figure 1 illustrate the experimental and analytical methods of concrete confining effect.

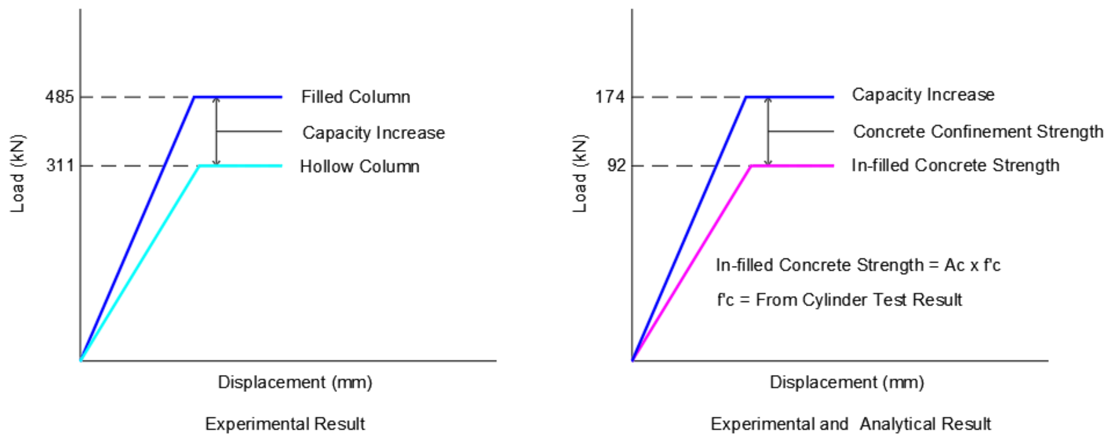
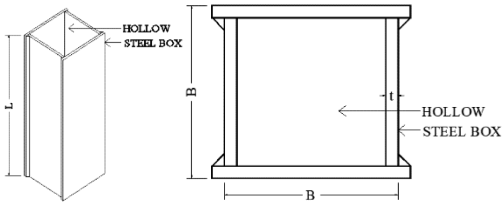


Fig. 1. Schematic Graph illustrate the concrete confinement strength of specimen -1.

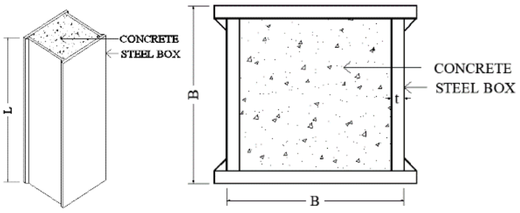
3. Experimental program

The test program comprised six hollow steel box column specimens and six concrete-filled fabricated box composite column specimens. Figure 2 and Table 1 display the geometric dimensions of these test column specimens. The column width 'B' ranged from 75mm to 150mm, while the Plate thickness varied between 4mm, 5mm and 6mm. To study the steel plate confinement effect, the width to thickness ratio spanned from 18 to 30. The steel box, fabricated in a local workshop, featured a square shape and was joined using fillet welding at the corners. For the 75mm size specimen, a length (L) of 375mm was maintained to achieve an L/B ratio of 5. The hollow box sections were denoted as HS- 100-4, indicating a box width (B) of 100mm and a plate thickness (t) of 4 mm. Conversely, the concrete-filled specimen was labelled as FVB-100-4, indicating filled with virgin brick aggregate concrete. Figure 2 and Figure 3 illustrate the sectional view of both hollow and filled specimens.



(a) (b)

Fig. 2. Hollow specimen (a) cross section (b) isometric view



(a) (b)

Fig. 3. Filled specimen (a) cross section (b) isometric view

(a) (b)

Fig. 4. a) Hollow specimen b) Filled specimen

The CFFSBC column specimens were tested for the concentric load to observe the failure peak load and axial deformation. The both hollow and concrete-filled fabricated steel box composite (CFFSBC) column specimen are shown in Figure 4.

Table 1
Geometric properties of test specimens

Sl. No.	Specimen ID	B (mm)	t (mm)	L (mm)	B/t Ratio	L/B Ratio
1 2	FVB-75-4 HS-75-4	75	4	375	18.7	5
3 4	FVB-100-4 HS-100-4	100	4	500	25.0	5
5 6	FVB-100-5 HS-100-5	100	5	500	20.0	5
7 8	FVB-125-5 HS-125-5	125	5	625	25.0	5
9 10	FVB-125-6 HS-125-6	125	6	625	20.0	5
11 12	FVB-150-6 HS-150-6	150	6	750	25.0	5

4. Experimental setup

All the specimens are axially loaded by the Universal Testing Machine (UTM) having the load capacity of 2000kN at the Materials testing laboratory of Dhaka University of Engineering Technology, Gazipiur. The load was applied as a displacement from the bottom of the specimens. One linear variable displacement transducer (LVDT) is used to record the axial displacement of the specimen for the applied axial load which is installed vertically parallel to the specimen. Two LVDT is installed horizontally in the middle of the specimen to read the lateral displacement of the specimen. A 1000 kN load cell was set up 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, all the load and displacement data were read and stored in a laptop. Two end plate were used at both ends of the specimen for transferring the load uniformly. The specimen was placed at the center of the UTM machine and used a split lever to position the specimen perfectly. Axial load was applied to the specimens up to the failure. During failure, the load starts decreasing with increasing the displacement. A schematic diagram of the test setup and the instrument setup with specimen before load applied are shown in Figure 5.

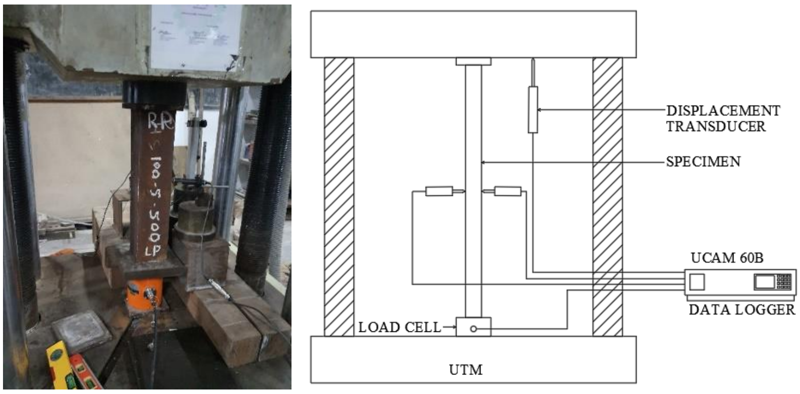


Fig. 5. Instrument setup.

5. Material properties

The concrete-filled fabricated steel box composite column consists of two primary components: the hollow steel box and the infill concrete block. Various codes detail the metallurgy standards for both steel and concrete materials. Regarding the steel materials, mild steel, alloy steel, low carbon, and high carbon steel can be utilized to fabricate the steel box component based on specific project requirements. Codes such as ACI, AISC and EC4 provide specific guidelines for determining the steel materials. In accordance with BNBC 2020, the strength range for steel plate materials is detailed in part VI Chapter 13.

Table 2
Peak load of test specimens

Sl. No	Specimen ID	Size B (mm)	t (mm)	L (mm)	B/t Ratio	L/B Ratio	Steel fy	Con. f'c	P_{Exp}
1 2	FVB-75-4 HS-75-4	75	4	375	18	5	250	20.5	485 311
3 4	FVB-100-4 HS-100-4	100	4	500	25	5	250	31.0	720 412
5 6	FVB-100-5 HS-100-5	100	5	500	20	5	250	20.5	734 511
7 8	FVB-125-5 HS-125-5	125	5	625	25	5	250	36.5	1392 623
9 10	FVB-125-6 HS-125-6	125	6	625	25	5	250	31.0	1466 768
11 12	FVB-150-6 HS-150-6	150	6	750	25	5	250	31.0	1764 920

5.1 Structural steel properties

ASTM A36 steel plates were utilized in this study, readily available in our local market. For the tensile strength test of the steel plates, three coupon samples with a thickness of 4mm were prepared and tested. the average yield strength (*fy*) recorded was 253MPa. Additionally, flat bar specimens from were tested, resulting in an average yield strength of 254MPa. For calculation purposes, the yield strength (*fy*) of the steel plate was considered as 250Mpa. In accordance with ASTM standards, the ultimate strength of plate was assumed to be 400MPa. These tensile tests on the plates were conducted at the materials testing lab of DUET.

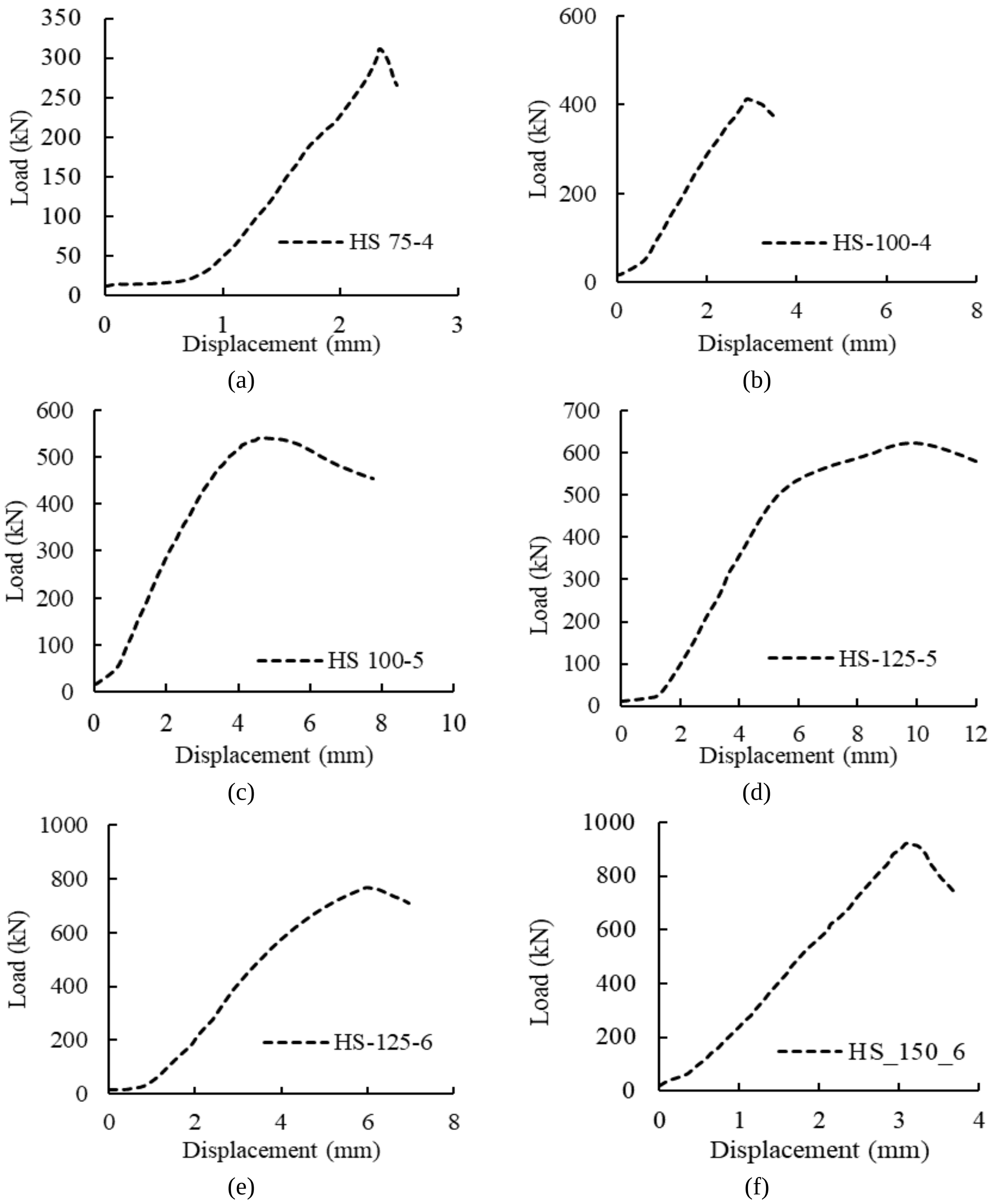


Fig. 6. Load displacement relation of hollow specimen.

5.2 Concrete properties

The purpose of this study was to utilize brick aggregate concrete in order to produce concrete with low strength. The concrete's mix ratio was altered in order to achieve varying degrees of strength, while keeping other factors such as water-cement ratio and additive constant. The selected mixing ratios were 1:2:4, 1:1½:3, and 1:1¼:2½, which were used to create concrete with different levels of strength. The construction utilized coarse aggregate with a size of ¾ down grade, in addition to sand with a fineness modulus (FM) of 2.5. The test methodology extensively utilized locally available cement. Experiments were performed on concrete cylinders with various mix ratios, yielding average strengths of 20.5 MPa, 31.0 MPa, and 36.5 MPa.

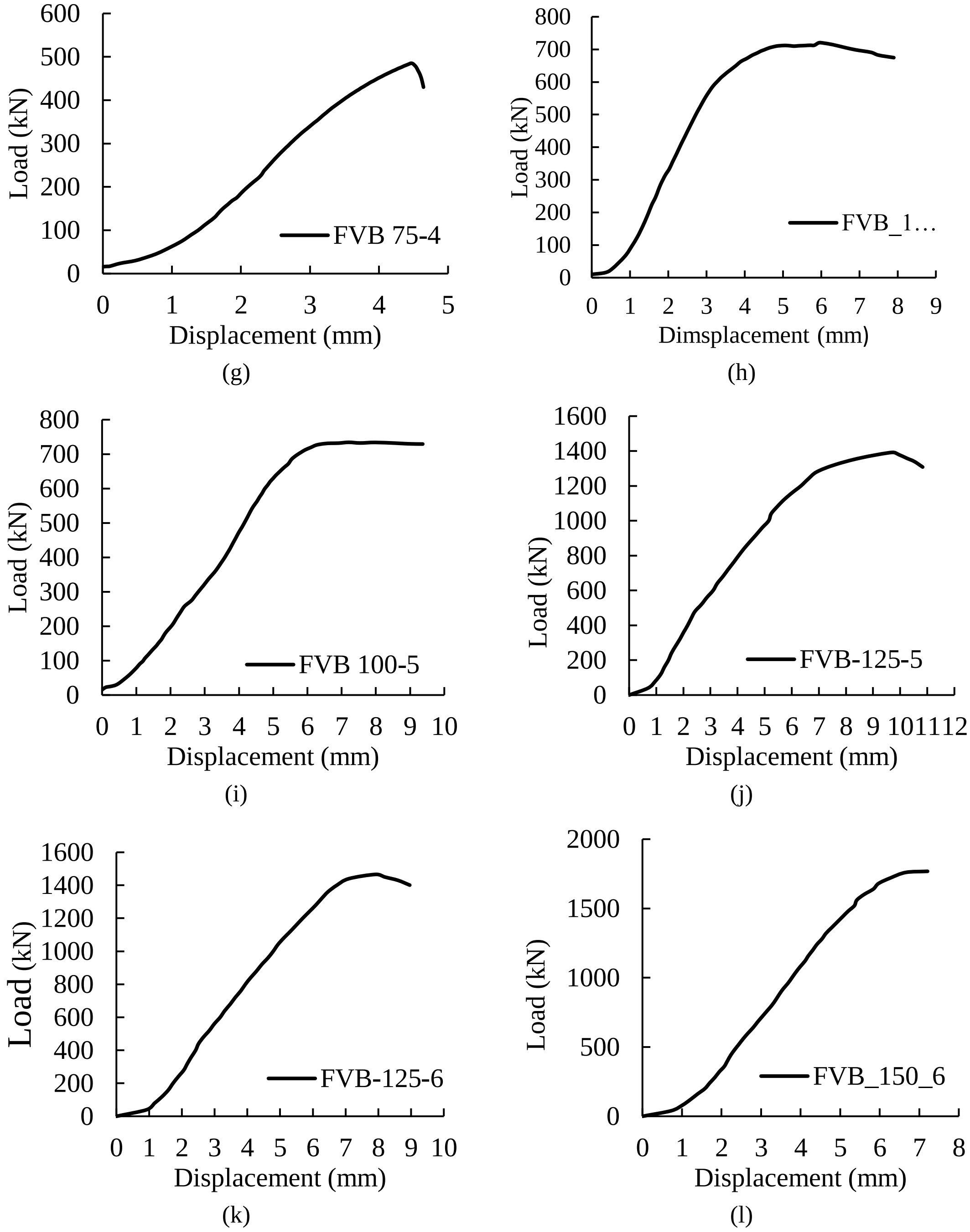


Fig. 7. Load Displacement Relation of Filled Specimen

6. Test result and discussion

Figure 6 and Figure 7 illustrate the load displacement relationship for both hollow and concrete-filled fabricated box composite (CFFSBC) column specimens. In the graph, the dotted line represents the load displacement relation for the hollow box specimens, while the solid line shows the relation for the concrete-filled box composite columns. The vertical axis represents the load data, while the horizontal axis displays axial displacement data. The peak load of each specimen was found from the test results, it is denoted by P_{exp}. Table 2 shows the corresponding maximum P_{exp} for all specimens. The maximum displacement is also recorded at this maximum peak load. Following the peak load, a subsequence decrease in load and continuous increase in displacement were observed. Initially, during the application of load, the displacement exhibited higher values for the first few points and did not follow a linear trend with the applied load. Consequently, this phase at the beginning of the load-displacement curve resulted in the formation of an ‘S’ curve.

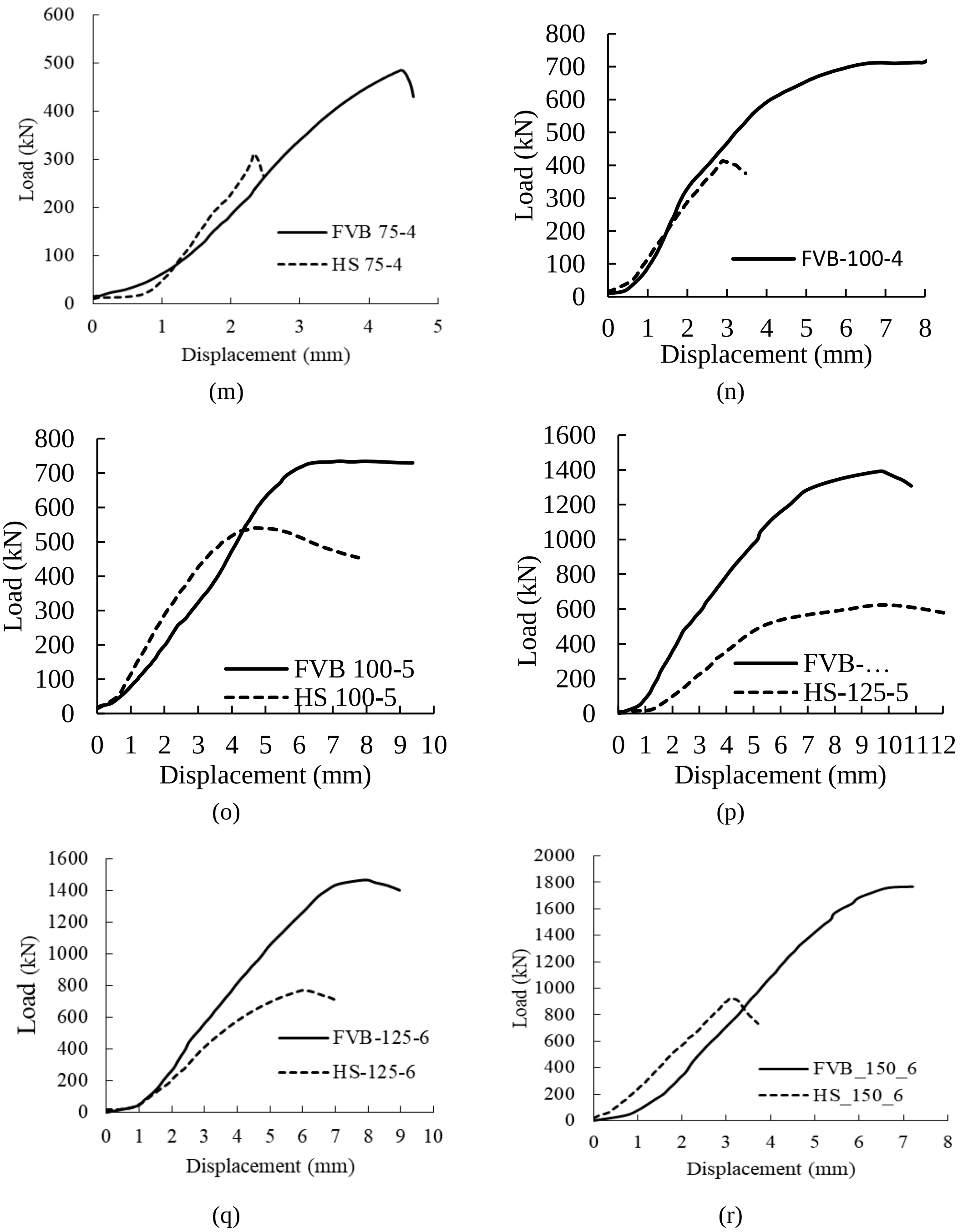


Fig. 8. Load displacement relation of hollow and filled specimen.

The experimental results illustrate the axial load-carrying capacity and axial deformation of both hollow and filled specimens. The load capacity of the steel box was derived from the hollow section's results, while the additional strength due to infill concrete was calculated from the difference between the values of the hollow and filled specimens. In the initial set of results, the failure strength of the CFFSBC column was 485kN, whereas the hollow steel box specimen exhibited a failure strength of 311kN. This indicates an increased strength of 174kN for the filled specimen. This additional capacity is attributed to the presence of infill concrete and the combined effect of concrete confinement and steel-concrete interaction. Through analytical calculations, the sectional capacity of the infill concrete block was determined, revealing a maximum strength of 92kN. Notably, this capacity surpasses the concrete capacity by 82kN, representing the concrete confinement strength. The steel box exerts confinement pressure uniformly around the concrete block, while the infill concrete prevents inward buckling of the steel box, delaying both local and global buckling phenomena.

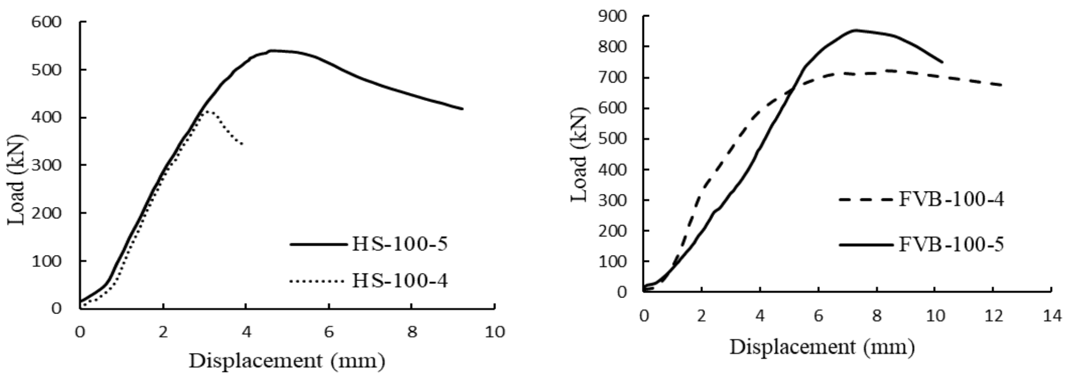
Table 3
Experimental and analytical results

Sl. No	Sp. ID.	Size B	t	Len. L	B/t Ratio	L/B Ratio	Steel fy	Con. f'c	PExp	PAna/ ACI	PExp/ PAna
1	FVB-75-4	75	4	375	18.5	5	250	20.5	485	386	0.80
2	HS-75-4								311	308	0.99
3	FVB-100-4	100	4	500	25.0	5	250	31.06	720	631	0.88
4	HS-100-4								412	408	0.99
5	FVB-100-5	100	5	500	20.0	5	250	20.5	734	653	0.89
6	HS-100-5								511	512	1.00
7	FVB-125-5	125	5	625	25.0	5	250	36.68	1392	1049	0.75
8	HS-125-5								623	637	1.02
9	FVB-125-6	125	6	625	25.0	5	250	31. 06	1466	1105	0.75
10	HS-125-6								768	768	1.00
11	FVB-150-6	150	6	750	25	5	250	31.06	1764	1420	0.81
12	HS-150-6								920	918	1.00

Table 4
Confinement strength results

Sl. No.	Specimen ID	B (mm)	t (mm)	L (mm)	B/t Ratio	L/B Ratio	fy MPa	f'c MPa	f'cc MPa	% Increase
1	FVB-75-4	75	4	375	18.75	5	250	20.5	38.0	85.82
3	FVB-100-4	100	4	500	25.00	5	250	31.0	36.5	17.26
5	FVB-100-5	100	5	500	25.00	5	250	20.5	27.0	33.55
7	FVB-125-5	125	5	625	25.00	5	250	36.5	58.0	58.44
9	FVB-125-6	125	6	625	20.83	5	250	31.0	54.5	76.05
11	FVB-150-6	150	6	750	25.00	5	250	31.0	44.5	43.70

Consequently, both materials mutually reinforce each other. The confinement strength was analytically calculated for each filled specimen, and Table 3 shows the confinement results. It was observed that specimen with a lower B/t ratio experienced higher confinement strength, and concrete with lower strength experienced higher percentage of confinement strength. Specimen 1 (FVB-75-4), filled with brick aggregate concrete having a concrete strength *f'c* of 20.5MPa, yielded a calculated concrete confinement strength *f'cc* of 38.0MPa, marking an increase of 85.8% in confinement strength. Specimen 3 (FVB-100-4), also poured with brick aggregate concrete having a concrete strength *f'c* of 31.0MPa, exhibits a confinement strength *f'cc* of 36.5MPa, reflecting a 17.26% increase. Similarly, specimen 7 (FVB-1125-5), poured with brick aggregate concrete having a concrete strength *f'c* of 36.5MPa, displayed a confinement strength *f'cc* of 58.0MPa, indicating a 58.44% increase. Hence, it is evident that low strength concrete exhibits higher confinement strength. Figure 5 shows the load displacement relations of the hollow specimens, while Figure 6 illustrate the load displacement relation of filled specimens, Figure 8 compare hollow and filled specimens, and Figure 9 showcases hollow and filled specimens fabricated with 4mm and 5mm plates. The axial load capacity of filled specimen appears to depend on both concrete strength and the width to thickness ration of the specimen. Remarkably, the test result indicates a 24% increase in the axial load capacity for hollow specimens 4 and 6 with a plate thickness variation from 4mm to 5mm. Additionally, filled specimen 3 and 5 exhibited an increase in concrete confinement strength of 17.26% and 33.55%, respectively. Specimen 5, which was poured with low-strength concrete, experience higher confinement strength. Table 4 provides the percentage of confinement strength observed in this study.



(s) (t)

Fig. 9. Load displacement relation of 4mm and 5mm plate hollow and filled specimen.

7. Conclusions

Concrete confinement strength has been observed through using the experimental peak load. The axial strength has shown an increase in concrete filled fabricated steel box composite (CFFSBC) column. It was also observed that an increase in concrete strength differ the confining effect. The concrete confinement strength was observed in all CFFSBC column, indicating that low strength concrete exhibits a higher confinement effect.

- The capacity of CFFSBC columns has been observed to increase, depends on the concrete strength and steel plate thickness. This study found an increase in axial strength across all columns, ranging from 42.6% to 74.5% higher strength increased than the hollow box column.
- The axial strength varied due to the variation in the B/t (width-to-thickness) ratio, increasing with the plate thickness. Additionally, the concrete confinement strength was found to increase with greater plate thickness.
- On average, the strength of all columns increased by around 50%. The maximum concrete confinement observed was 85.82% in low strength concrete-filled column specimen.
- Different strength concrete infills exhibited varying levels of confinement strength, with low-strength concrete infill showing a higher percentage of confinement strength.

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