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FABRICATED STEEL BOX COMPOSITE COLUMN AND ITS ADVANTAGES - BANGLADESH PERSPECTIVE

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ABSTRACT

Tall buildings are now widely constructed in all over the world. The construction materials strength is the key factor to build the high rise structures. Concrete has compressive strength, stiffness and stability whereas steel has tensile strength, ductile behavior but both of those behaviors are not found in one material.As a result the composite materials are requiredto build tall buildings. The combined behavior of steel and concrete is reduced the member size and provide more strength for constructing tall buildings. Steel is widely used as reinforcement in reinforced concrete structure. On the other hand, in steel building construction system, steel is used to build the main frame work to resist the structural forces. Steel construction is rapid and speedy work in respect to reinforce concrete construction work. So, considering all the behavior of steel and concrete, a new type of member with different shape and geometry of steel plate with concrete called composite members is developed. The composite column is one of them. There are three type of composite column according to their construction, geometry and placement of steel and concrete. The behavior of concrete is changing with it placement in column. The concrete confinement is a factor to implement the total concrete strength of a member. The strength of confined concrete is more than unconfined concrete. As a result the concrete filled box composite column is contributing better strength than other composite columns. The steel box composite column can be constructed in hot rolled tube or box section. But for the shape and size of the hot rolled box is fixed in its construction process. In cold rolled process, the steel box is fabricated with steel plate of different thickness like the built up members. As a result because of different typeand shape, different combination of plate can be made to fabricate the steel box. So the fabricated box is now popular for the box column construction all over the world. Also the box can be fabricated manually or automatically. There is some automated machine is available to fabricate the steel box.

Keywords:*steel box, fabrication, concrete properties,finite element,composite, ANSYS,*

1. INTRODUCTION

Tall buildings would be impossible without advances in technology. The composite steel frame skeleton was nothing,but a structural revolution when it was developed in Chicago in the late nineteenth century, and it has been evolving ever since. Early tall buildings constructed with cast iron framing were susceptible to fire and it was discovered that encasing the iron with concrete increased the material's resistance to fire. United State of America introduced composite construction system in 1894. After that it used in many tall building structures all over the world. Experimental researches were carried out on the composite column for different shape and size, different materials strength, different ratio of steel and concrete proportion. The experimental and theoretical research were conducted on concrete filled steel tubular column from 1960 to 2000 by many researchers. Furlong (1967) conducted tests on the ultimate loads of concrete-filled steel box columns. Knowles and Park(1969), Tomii et al. (1977), Shakir-Khalil and Mouli (1990) and Schneider (1998) have conducted tests on concrete-filled steel tubular column. Ge and Usami (1992), Uy and Bradford(1995) and Uy (2000) studied on local bucking of concrete-filled steel box columns.

Liang and Uy (1998) proposed effective width models for the analysis and design of steel plates in concrete-filled thin-walled steel box columns.Structural steel and its use in Bangladesh can be traced back from the British period with its use in bridges and railway projects. After Bangladesh established and from the early nineties structural steel is starting use in steel buildings mainly gable frame structures. At that time, those steel section are imported from abroad. After ninety, local fabrication factories develop and started the fabrication of built up section. Using hot rolled plates those members are fabricated. The source of plate materialswas available in local market, and ship breaking, and some are imported plates from abroad. Hot rolled sections were also usedas per project requirement. Bangladesh has no hot rolled steel section production factory, so all hot rolled steel sections wereimported from abroad. Now-a-days Bangladesh construction industries developed the steel construction system, many multistoried steel building is constructed and start using the composite members in the structural system. For the fire rating requirements concrete encasing steel column is introduced first. Again the same type of column introduce for retrofitting of the weak structures.Now the designer start using the composite column in the design of new structures. Recently Concrete filled fabricated steel box composite column (FSBCC) is introduced in buildings and a renowned prefabricated steel company Builtrade Enginering Limited is started fabrication of FSBCC. Composite columns can have high strength for a relatively small cross-sectional area, meaning that usable floor space can be maximized. There are several different types of composite column, the most common being a hollow section steel tube which is filled with concrete shown in Figure 1 or and open steel section encased in concrete. The concrete infilledincrease the compression resistance of the steel section and preventing the steel from buckling.

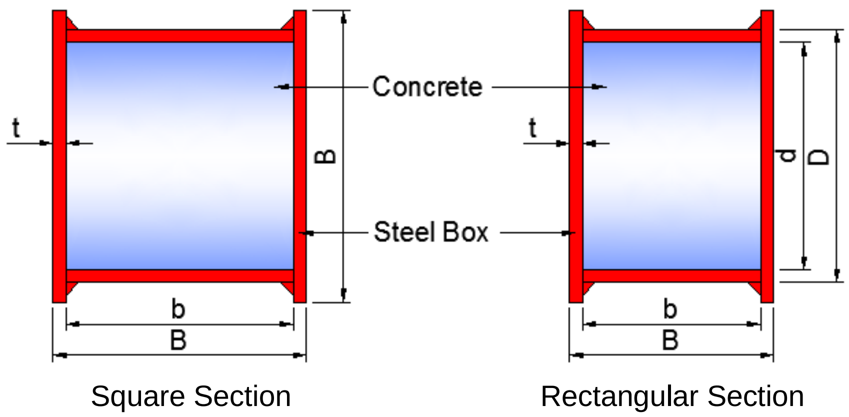


Figure 1: Concrete-filled steel box columns

2. TYPE OF COMPOSITE COLUMN

Two basic types of composite columns are mostly used in buildings: those with the steel section encased in concrete and those with the steel section filled with concrete.One of the common and popular columns is the encased steel profile as shown in Figure2, where a steel H-section is encased in concrete. Sometimes, structural pipe, tube, or built up section is placed instead of the H-section.In addition to upholding a proportion of the load acting on the column, the concrete encasementenhances the behavior of the structural steel core and horizontal bar reinforcement, and so making it more effective against both local and overall buckling. The load-bearing concrete encasement performs the additional function of fireproofing the steel core.The cross sections, which normally are square or rectangular, must have one or extra longitudinal bars placed in every single corner and these have to be tied by lateral ties at regular vertical intervals in the manner of a reinforced concrete column. Ties are effective in rising column strength, confinement and ductility. Furthermore, Ties stop the longitudinal bars from being displaced during construction and they resist the tendency of these same bars to buckle outward under load, which would cause spalling of the outer concrete cover even at low load levels, remarkably in the case of eccentrically loaded columns. It will be noted that these ties will be open and U-shaped. Otherwise, they might not be installed, because the steel column shapes will have always been erected at an earlier time.

2.1 Concrete Filled Composite Columns

In this type of composite columns, a steel pipe, steel tubing, or built up section is filled with concrete showed in Figure3.The most common steel sections used are the hollow rectangular and circular tubes. Filled composite columns may be the most efficient application of materials for column cross sections. It provides forms for the inexpensive concrete core and increases the strength and stiffness of the column. In addition, because of its relatively high stiffness and tensile resistance, the steel shell provides transverse confinement to the concrete, making the filled composite column very ductile with remarkable toughness to resist the loads. Fabricated Steel box composite column is a built up hollow box section, assemble with four steel plate and bearing stiffeners in bothe ends of column. Some intermediate stiffeners also given in the column to transter the concrete load to steel box and reduce the plate buckling. FSBCC has the flexibility to make any size with different combination of steel plate with the different width thickness ratio.

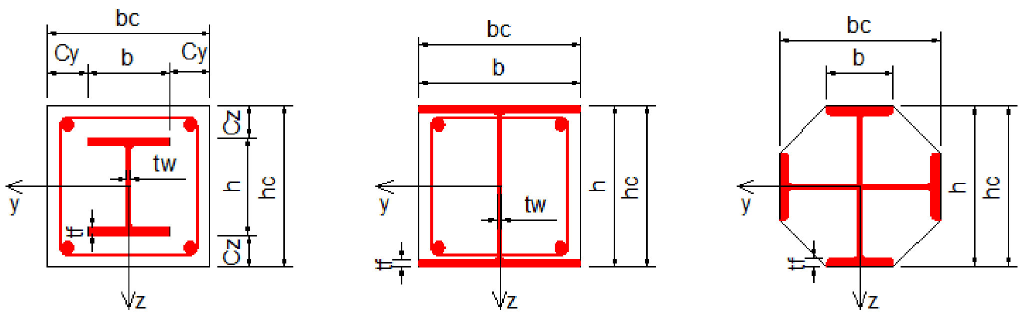


Figure 2:Typical Section of Fully and partially encase composite column

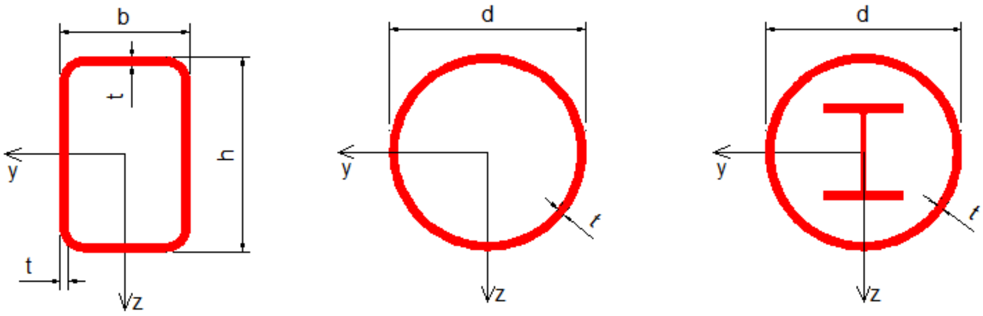


Figure3: Typical Section of Concrete fill composite column

3. FABRICATED STEEL BOX COMPOSITE COLUMN IN BANGLADESH

In 2016 the first FSBCC has been constructed in dormatory Building at BSRM Bilade Casting Plant, Chittagong. After that, in 2017 Bachelor quarter of Jessore Air Force Base, started and the construction work is running Figure 4. Special type box fabrication machine is invented, using those machine, four steel plates assemble the box and welded automatically. So the quality of welding is found error free. The columns can be fabricated with all require connectivity and after site erection, concrete is filled by pumping. Steel-concrete composite column are widely use in high rise building and bridges. Tall building construction is increased all over the world and the structural member size became larger in the structures according to its height and loading. Reinforced concrete structure and steel structures are commonly used for construction of high rise buildings. High strengthmaterial is introduced in construction industries to build the high rise structures. From the continuous research on material and its behavior the composite material is found as hybrid materials for construction work

Figure4: Concrete-Filled Fabricated Steel Box Composite Column (FSBCC)Bachelor Quarter, Air Force Base, Joshore Bangladesh 2017

4. DESIGN AND CODE FOR FSBCC

Rectangular and circular hollow sections are most commonly used, although rectangular sections are beneficial for being having flat faces suitable for end plate beam to column connections. However, fin plates can be used for rectangular and circular shape. Composite structure design procedure are describe in AISC LRFD(2010), ACI 318(2014), Euro code-4(2005), Canadian Standard Association CSA (2009), Architectural Institute of Japan(AIJ 2005) and Egyptian code(2012).The AISC-LRFD (2010) defines a composite column as a steel column fabricated from rolled or built up steel shapes and encased in structural concrete or fabricated from steel pipe or tubing and filled with structural concrete. In this specification, the design method for composite columns is based on the ultimate strength of the materials of the cross section and takes into account the inelastic material properties with the required design loads as factored service loads. It contains the latest design approach of structural steel based on the ultimate strength concept.

The nominal strength of a composite cross section is calculated from the ultimate resistance to load, and reduction capacity factors related to material properties and characteristics of member failure are applied to the nominal strength of the cross section. The strength provisions for concrete-encased composite columns as recommended in Chapter I of the AISC-LRFD (2010). In order for dissimilar materials to act in a composite manner, forces must be transferred between the materials so that they achieve a state of internal equilibrium with one another. Previous editions of the AISC-LRFD specification briefly address load transfer; however, these provisions are quite limited in scope and clarity. The AISC-LRFD (2010) specification significantly expands load transfer requirements in a new section. Clear guidance is now provided for the allocation of forces between steel and concrete sections as well as for force transfer mechanisms used for composite members.

The design of composite column is based on the design equation for steel columnsAISC-LRFD (2010). The selenderness and area parameters are modified for the presence of concrete. Load transfer should be provided by direct bearing at the connections. Compressive strength for non-compact filled members is determined in accordance with AISC Specification Section 2.2b(b). The capacity calculation of FSBCC is calculated by the equations as;

$Pp = fyAs + C_2 f'c \left(Ac + Asr \frac{Es}{Ec}\right)$ where, P_p is the column capacity at $C_2 = 0.85$ for rectangular section.

$Py = fyAs + 0.7 f'c \left(Ac + Asr \frac{Es}{Ec}\right)$ P_y is the column capacity at $C_2 = 0.7$

$Pno = Pp - \frac{Pp - Py}{(\lambda r - \lambda p)}(\lambda - \lambda p)^2$ where $\lambda = \frac{bi}{t}, \lambda r = 3\sqrt{\frac{E}{fy}}, \lambda p = 2.26\sqrt{\frac{E}{fy}}$

$C_3 = 0.6 + 2\left(\frac{As}{Ac + As}\right)$ where $C_3 \leq 0.9$

$EI_{eff} = E_s I_s + E_s I_{sr} + C_3 E_c I_c$

$P_e = \pi^2 (EI_{eff})/(KL)^2$ where P_e is the buckling load of column

$P_n = P_{no} [0.658^{Pno/Pe}]$ where P_n is maximum load capacity of column

Where

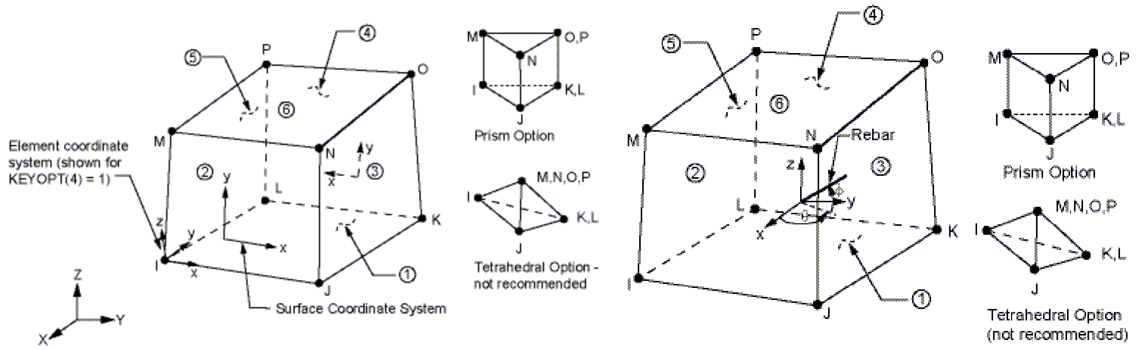
A_c = area of concrete mm^2
A_{sr} = area of continuous reinforcing bars, mm^2
A_s = area of steel section, mm^2
E_c = modulus of elasticity of concrete, MPa
E_s = modulus of elasticity of steel, MPa
EI_{eff} = effective moment of inertia rigidity of composite section, Kip-mm^2
f_{cu} = specified minimum concrete compressive strength, MPa
f_y = yield stress of steel section, MPa
f_{ysr} = specific minimum yield stress of reinforcing bars,MPa
I_c = moment of inertia of the concrete section, mm^4
I_s = moment of inertia of the steel section, mm^4
I_{sr} =moment of inertia of the reinforcing bars, mm^4
K = effective length factor
L = laterally unbraced length of the member, mm.

5.NUMERICAL MODEL OF COMPOSITE COLUMN

Finite element (FE) technique is becoming more and more popular in modeling of composite columns. There are some commercially available software for this work, such as ANSYS and ABAQUS. Three dimensional solid model analysis allows the direct modeling of the composite action between the steel and concrete components with different factors. The same allows for detailed simulation of composite members. In this type of analysis, the concrete core is commonly modeled with solid elements, while the steel tube is modeled with shell elements. The interface between the two materials is assembled together by some connector or interface elements to simulate the interaction between the steel and concrete components. Many researchers adopted solid model for simulating the static performance of composite columns. For example, Schneider(1998) presented an experimental and analytical study on the behavior of short, concrete filled steel tube columns concentrically loaded in compression to failure. 20-noded brick element and 8-noded shell element are adopted for simulating concrete and steel tube.

5.1 Element consider in numerical model

In this Numerical study ANSYS (APDL) and ANSYS Work Bench Version 15 is use to analysis all the models to verify and check the validity and accuracy of the finite elements results. The results are compared with the experimental result to predict the accuracy of the numerical analysis. The 3D model is used Solid elements for modeling the concrete and steel materials Figure 5. The solid is capable of cracking in tension and crushing in compression. The element is defined by eight nodes and has three degrees of freedom at each node. The concrete element SOLID 65 is simulate the behavior of concrete and SOLID 45 element is use to simulate the steel materials. The elements have plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. The parameters of the concrete and steel use in this study is, modulus of elasticity $E_c=4700\sqrt{f'c}$ in SI unit and $E_s = 2x10^5$Mpa.



(a) (b)

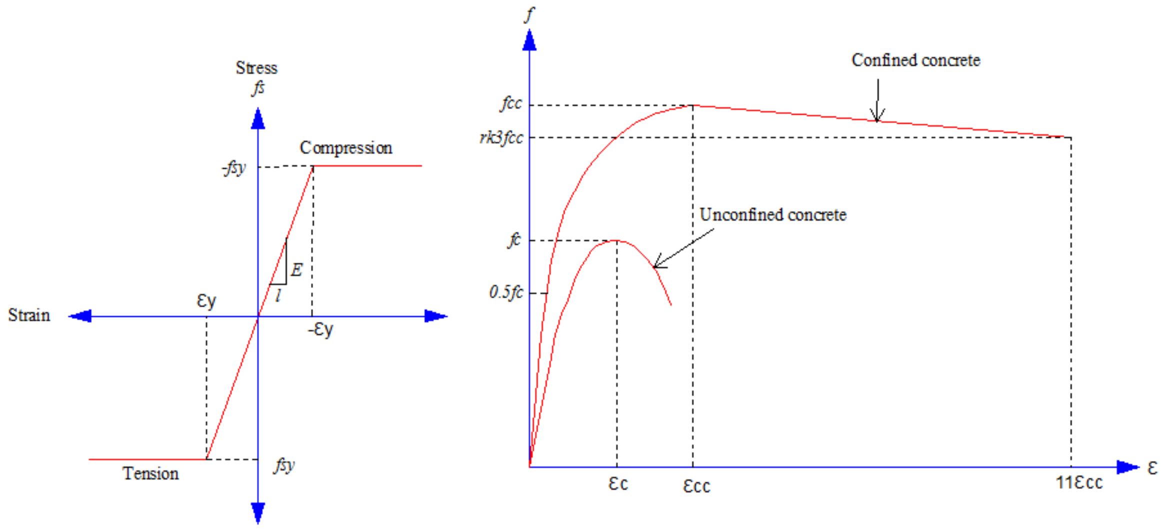
Figure 5: Elements Geomety (a) SOLID 65 and (b) SOLID45

5.2 Material models for structural steel

Modeling of the steel box has been carried out as an elastic-perfectly plastic material in both tension and compression. Mainly steel plate materials with different yield strength are used for fabricating the box. Steel is a ductile material which experience large inelastic strain beyond the yield point. So the true stress and logarithmic strain graph which is also called hardening curve is considering for the material behavior of steel. In ANSYS Parametric Design Language (APDL) bilinear and multi-linear stress strain curve can be used to analysis the steel materials. The stress-strain curve used for the steel box is shown in Figure6(a). The yield stress, modulus of elasticity, and Poisson's ratio of the steel box have been respectively taken as 252MPa, $2x10^6$MPa, and 0.3 that are identical to those in the corresponding experiment. VonMises yield criterion, an associated flow rule, and isotropic hardening have been also utilized in the nonlinear material model.

5.3 Material model for concrete

Material models for concrete are assumed that the confinement effect increases only the ductility of the concrete in concrete-filled steel box columns but not its strength (Tomii and Sakino, 1979). The multi linear stress-strain curve for concrete in concrete-filled steel box columns is shown in Figure 4. The stress-strain curve is modeled using the equation suggested by Mander et al. (1988). The compressive strength and modulus of elasticity of concrete have been respectively adopted as 25MPa and $23.5x10^3$MPa which are the same as those in the corresponding experiment. 6(b) shows the equivalent uniaxial stress-strain curves for concrete, which have been used in this study to model concrete.



(a) (b)

Figure 6: stress-strain curve (a) steel, (b) concrete

The confined concrete compressive strength, $f_{cc}$and the corresponding confined stain $\mathcal{E}_{cc}$is obtained from quations as shown below;

$f_{cc} = f_c + K_1 f_1$ where, K_1 is a factor

$\mathcal{E}_{cc} = \mathcal{E}_c\ (1+K_2\ \frac{f_1}{fc})$where, K_2 is a factor

The empirical equation has been used to determine the initial Young's modulus of confined concrete E_{cc}. The Poisson's ratio $\upsilon_{cc}$of confined concrete has been considered as 0.2.
E_{cc}=4700$\sqrt{f}_{cc}$

6. EXPERIMENTAL DATA

A set of experimental data is taken from the paper of Hasan Abdulhadi (2015), publish in the Journal (Internation Journal of Innovative Research in Science, Engineering and Technology)February 2015. The test specimen details are given in Table 1. The experimental and analytical data are shown in Table 2.

Tabel 1: Specimen detail of Hasan Abdulhadi(2015)

Square Sample	Width (mm)	Thickness (mm)	Length (mm)	Type of Concrete	fc Mpa	fy Mpa
SH-1	150	3	300	Hollow	-	252
SF-1-A	150	3	300	Normal concrete (A)	25	252
SF-1-B	150	3	300	High Strength concrete (B)	60	252
SH-2	150	4	300	Hollow	-	306
SF-2-A	150	4	300	Normal concrete (A)	25	306
SF-2-B	150	4	300	High Strength concrete (B)	60	306
SH-3	150	5	300	Hollow	-	285
SF-3-A	150	5	300	Normal concrete (A)	25	285
SF-3-B	150	5	300	High Strength concrete (B)	60	285

Table 2: Axial Load at failure and attendant deflectioncarried by the specimen of Hasan Abdulhadi (2015)

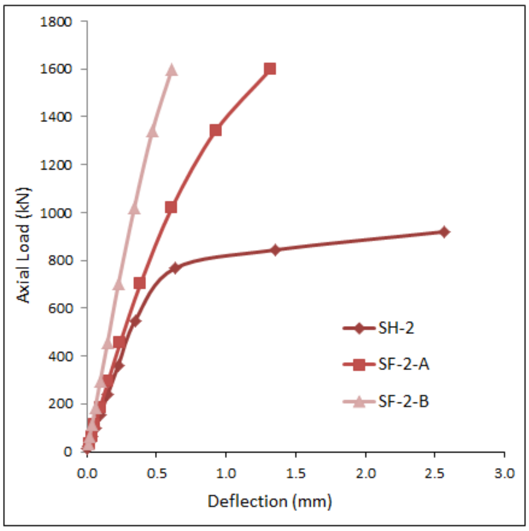
Samples	**Axial load at failure (kN)**			**Deflection attendant at maximumload(mm)**		
	P_{exp}	P_{ana}	P_{ana}/P_{exp}	Δ_{exp}	Δ_{ana}	$\Delta_{ana}/\Delta_{exp}$
SH-1	579	611	1.05	2.00	1.86	0.93
SF-1-A	1125	1296	1.15	3.31	3.40	1.02
SF-1-B	1361	1486	1.09	2.81	2.96	1.05
SH-2	620	662	1.06	2.11	2.24	1.06
SF-2-A	1215	1326	1.09	3.00	3.48	1.16
SF-2-B	1543	1724	1.11	2.91	3.23	1.10
SH-3	675	737	1.09	1.70	1.94	1.14
SF-3-A	1300	1450	1.11	2.61	2.90	1.11
SF-3-B	1615	1816	1.12	3.10	3.35	1.08

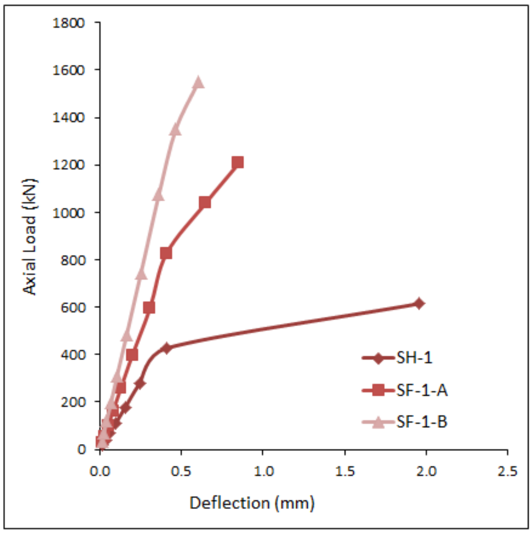
7. NUMEICAL RESULTS AND DISCUSSION

Using same geometry and material properties shown in Table 1, Table 2 and ANSYS APDL having version of 15 numerical analysis of a number of specimens are carried out. From the numerical analysis, a set of result found and shown in Table 3. Load carried capacity and deflection characteristic of each of the specimen are recorded and compared with experimental data of Hasan Abdulhadi (2015). The comparison is found well agreed and the variation is insignificant in respect of load carring capacity. The data received are plotted in the form of load versus deflectoion curves as shown in Figure 7, in which the ordinate indicates applied load and the abscissa indicates deflection attendant at different ranges of load.

Table3: Axial Load at failure and attendant deflection data found fromthis analytical study

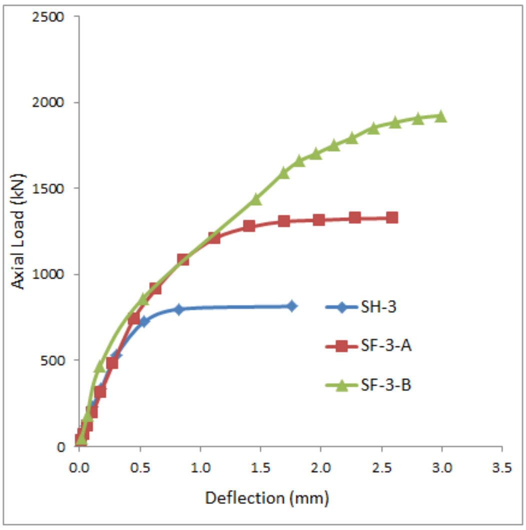
Samples	Axial load at failure (kN)			Deflection attendant at maximum load(mm)		
	P_{exp}	P_{ana}	P_{ana}/P_{exp}	Δ_{exp}	Δ_{ana}	$\Delta_{ana}/\Delta_{exp}$
SH-1	579	614	1.06	2.00	1.95	0.97
SF-1-A	1125	1206	1.07	3.31	0.88	0.26
SF-1-B	1361	1553	1.14	2.81	0.60	0.21
SH-2	620	627	1.01	2.11	2.12	1.00
SF-2-A	1215	1342	1.10	3.00	0.92	0.30
SF-2-B	1543	1599	1.03	2.91	0.61	0.20
SH-3	675	750	1.11	1.70	1.89	1.11
SF-3-A	1300	1326	1.02	2.61	2.59	0.99
SF-3-B	1615	1883	1.16	3.10	2.61	0.84





(a) Specimens SH-1, SF-1-A and SF-1-B

(b) Specimens SH-2, SF-2-A and SF-2-B



(c) Specimens SH-3, SF-3-A and SF-3-B

Figure 7: Load deflection curves for different type of specimens

8. CONCLUSIONS

On the basis of this study the following conclusions may be drawn for FSBCC:

- The ultimate strength of FSBCC depends on the plate thickness of fabricated steel box;
- Ultimate load capacity of FSBCC is also depends on the compressive strength of the concrete;
- The width thickness ratio of plate effect the strength of the FSBCC;
- The finite element method is an effective way to predict the behavior of FSBCC;
- In Bangladesh, Tall building or High rise buildings and factory buildings can be constructed with Fabricated SteelBox Composite Column.

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