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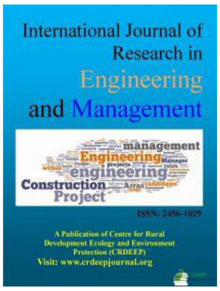

Full Length Research Paper

Experimental Test on Steel Hollow Sections Filled with Sand and Epoxy Materials

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ABSTRACT

Composite columns such as concrete-filled steel tubes were adopted in many building constructions in recent years because of carrying high loading with the ability to resist buckling. Some researchers used the sand to fill in steel tube columns to improve the behavior of composite columns. In this research, the behavior hollow steel sections filled with sand and epoxy resin mix was studied. A total of 8 specimens have been tested, as follows: 4 hollow tubes were tested for axial load compression, 4 were filled with epoxy-sand core. The main parameter studied is the height of the specimen to width ratios (h/b= 4, 8, 12, and 16). Based on test results obtained, there is a clear enhancement in the behavior of steel hollow section filled with sand and epoxy resin mix also, it is confirmed that tube length has a considerable effect on the bearing capacity and the failure mode. In all test tubes, fracture occurred by the convex local buckling of the steel section due to the outward thrust of the filling material.

Introduction

The use of concrete-filled steel tube (CFST) columns has been widely used in many modern structures. Their use provides high strength, high ductility, high stiffness and full usage of construction materials. In addition to these advantages, steel tubes surrounding concrete columns eliminate permanent formwork, which reduces construction time. Furthermore, steel tubes not only assist in resisting axial loads but also provide confinement to the concrete. The initial incorporation of composite behavior in columns utilizes the capacity of the steel section in combination with concrete. Further studies revealed that under compressive loads, the capacity of steel sections could be significantly improved for both local and global stability due to the restraining effect resulting from the concrete section as stated in [1-9]. Other researchers used pure polymers like epoxy as filler materials to the steel tubes [10 and11]. From another side, some researchers used sand to fill steel tubes in order to improve the different buckling modes of the steel tube column [12, 13, 14 and 15].

In this paper sand with epoxy resin mixes have been used to fill the hollow steel section to enhance the different buckling modes. Filling hollow steel columns with Sand and epoxy resin mix have given a range of advantages, including speed of construction, lightweight, high adhesion, low shrinkage, high tensile strength, and high ductility. It also has outstanding structural performance characteristics, including high stiffness and strength. Furthermore, it provides high ductility that avoids the modes of premature brittle failure and improves the inelastic and post-yield behavior of different members, which is necessary for the system as a whole to reach the plastic plateau.

Material Properties

To determine the mechanical properties of sand and epoxy resin mixture, 12 cubes 158 x 158 x 158 mm were cast for four different epoxy to sand ratios by weight which are 1:25, 1:50, 1:100, and 1:150. To determine the average compressive strength and the young's modulus mixture, 3 cubes for each mixing ratio were tested. The sand and epoxy resin mix compressive strength (F_{cu}) and Young's modulus (E) were shown in table 1. Mixing, casting, and testing of sand and epoxy resin mix cubes are shown in figure 1. To determine the maximum load capacity of the cubes, a 2000 kN universal testing machine has been used. The cubes were tested under compression.

At the beginning of loading, there were no visible cracks on the surfaces of the test cubes. By applying load gradually, small and vertical cracks appeared at the cube center. Cracks expanded towards the upper and the lower parts and finally, failure occurred. Steel tensile coupons were cut from flat steel sheet before manufacturing. Coupons test results show that, the mean steel yield strength (F_y) is equal to 240 MPa and the ultimate strength (F_u) is 360 MPa. Steel young's modulus is 210000 MPa.

Table. 1 Results of Epoxy-Sand Ratios Cubes Test

Epoxy-Sand Ratio	Average Crushing Load (KN)	Average Compressive Strength (F_{cu}) (MPa)
1:25	230	8.9
1:50	95	3.7
1:100	35	1.4
1:150	11	0.5

Casting of mixture — Placing of Mixture — Testing of Mixture Cube

Fig 1. The Mixing, Casting, And Testing Of Sand and Epoxy Resin Mix Cubes

Experimental Program

In order to determine the enhancement of hollow steel section filled with sand and epoxy resin mix, eight square hollow and composite columns have been constructed and tested under concentric axial compressive loads. The experimental program was divided into two groups. Figure 2 shows the first group, which consists of 4 control specimens of hollow steel columns and the second group consists of 4 control specimens of composite columns as shown in figure 3. Dimensions of the 4 specimens were defined to the study the effect of height-to-width ratios of columns on its strength. As shown in Table 2, the different values of h/b are 4, 8, 12, and 16. For all composite columns, epoxy to sand ratio considered 1:100.

A universal test machine of 2000 kN was used to test the 8 specimens and investigate the behavior of specimens as shown in Figure 4. Dial gauge Instruments are used to measure vertical and horizontal deformations. The vertical displacement of columns, as well as the local outer displacement of one side of the steel tube at different positions was determined. For each specimen, four dial gauges of 0.01 mm accuracy were used. Dial gauge (1) placed vertically on the machine's lower movable bearing plate to measure the shortening of the column compared to the other unmoved bearing plate. The other three dial gauges (2, 3, and 4) were placed horizontally along the length of the column at levels h/4, h/2 and 3h/4 on one side at the middle width of the steel tube.

For simplicity, each sample should have an independent classification consisting of a letter followed by a series of numbers such as C [1000-120-1-100] where the letter "C" is the composite column or "H" is the hollow column. Numbers following the letter are representing column height, column width, steel thickness, and sand ratio to epoxy unit weight respectively.

Table 2. Geometric and material properties

parameter	Specimens	b/t	h/b	Mix Ratios	F_{cu} (MPa)	F_y (MPa)
	H [500-120-1.5]	80	4	--	--	240
	H [1000-120-1.5]	80	8	--	--	240
	H [1500-120-1.5]	80	12	--	--	240
	H [2000-120-1.5]	80	16	--	--	240
	C [500-120-1.5-100]	80	4	1:100	1.7	240
	C [1000-120-1.5-100]	80	8	1:100	1.7	240
h/b ratios	C [1500-120-1.5-100]	80	12	1:100	1.7	240
	C [2000-120-1.5-100]	80	16	1:100	1.7	240

Experimental Results

Failure Modes

Different shapes for hollow steel tubes and steel tubes filled with sand and epoxy resin mix were observed for composite sections. Failure was initiated by wall local buckling of the hollow section then followed by crushing in the filling material.

As shown in Figures 5, 6, 7, 8, it is clear that the hollow and composite columns failure is due to local buckling. For hollow steel specimens, the lateral deformations are in the form of an inward local two-sided buckling wave, and an outward local buckling wave on the other two sides. The local buckling wave along the length of the column is double curvature, with length near the width of the tube. For specimen H [2000-120-1.5] (h/b = 16), a different pattern occurred. The global buckling is observed clearly followed by the occurrence of the local buckling of the column. While for composite columns all specimens were failed due to outward local buckling. The presence of the filling material prevented the occurrence of the inward buckling. The local buckling initiated mostly near the bottom end in the four sides of the tube. It is identical to the local buckling of a clamped plate. The failure sequence started first, steel tube locally buckled then the filling material crushing occurred later at the ultimate load. For the filling material, it is noticed that all cores failed crushing at the same location of the steel tube local buckling.

Figure 8 shows section in the specimens after failure, it is clear that steel wall local buckling and filling material crushes near column end. For hollow specimen H [2000-120-1.5] a global buckling occurred followed by local buckling of the column. But in composite specimen C [2000-120-1.5-100] outward local buckling only occurs. The presence of the filling material enhances the resistance of the section and present global buckling to occur.

Fig 2. Specimens of Hollow Steel Columns

Fig 3. Specimens of Composite Columns

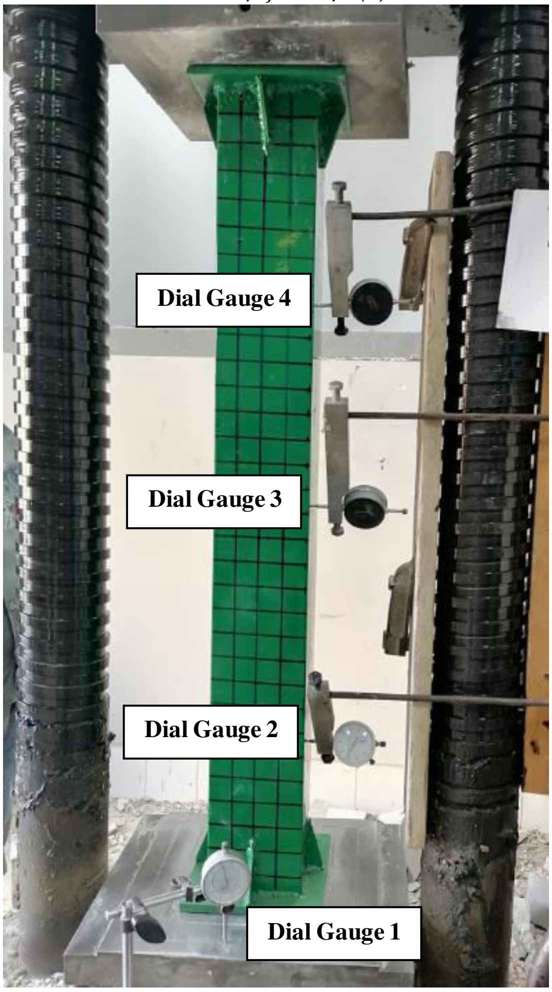

Fig 4. Dial Gauges Arrangement for Specimen

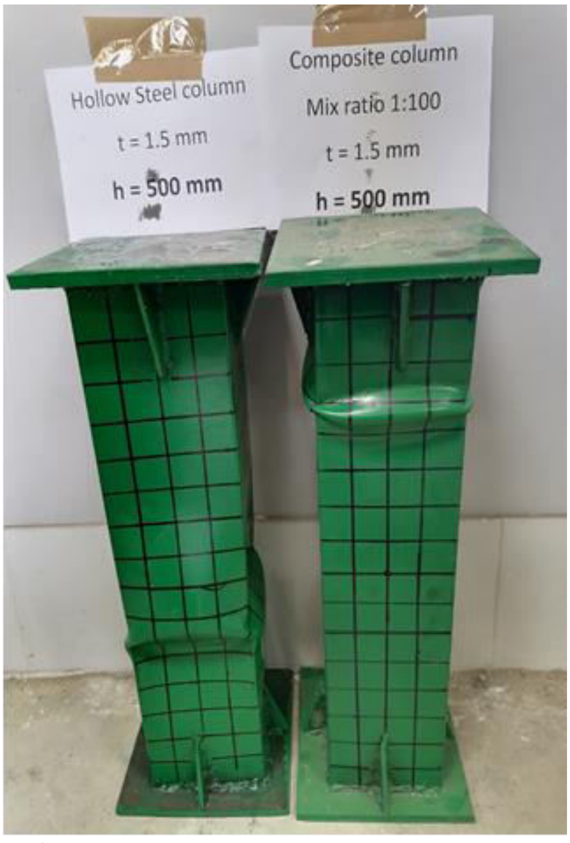

Fig 5. Failure mode of section h/b = 4

Fig 6. Failure mode of section h/b = 8

Fig 7. Failure mode of Section h/b = 12

Fig 8. Failure mode of Section h/b = 16

Effect of height to width Ratios (h/b) on Composite Column strength

The effect of adding epoxy-sand filling on square hollow steel columns with different h/b ratios (4, 8, 12, and 16) is studied. The maximum experimental loads attained by all specimens are summarized in table 3 and are denoted by P_u.

Figure 9 shows the relationship between P_U and different h/b ratios for both hollow and composite specimens. The ultimate load of composite columns is 175, 160, 142, and 130 kN for h/b = 4, 8, 12 and 16 respectively. While the ultimate load of hollow steel sections is 118, 98, 85, and 75 kN for h/b = 4, 8, 12 and 16 respectively. The results show a significant enhancement in the ultimate load of the hollow steel columns filled with sand and epoxy resin mix. It noted that specimens with greater height to width ratio (h/b=16) have gained strength more than specimens with smaller ones after filling sand and epoxy resin. That's because the failure of hollow specimens with high h/b is controlled by global buckling. Presences of sand - epoxy core enhance composite section behavior and prevent the occurrence of global buckling.

Figure 10 shows the relationship between P_C / P_H and different h/b ratios. The results show that specimen C [500-120-1.5-100] gained 45% increase in strength compared to specimens H [500-120-1.5]. Specimen C [2000-120-1.5-100] strength is increased with 73% more than specimen H [2000-120-1.5].So sand and epoxy resin mix increase column strength signification.

Table 3. Results of test specimens

parameter	**Specimens**	**b/t**	**h/b**	**Mix Ratios**	**P_U (kN)**	**$\frac{P_C}{P_H}$**
	H [500-120-1.5]	80	4	--	118	-
	H [1000-120-1.5]	80	8	--	98	-
	H [1500-120-1.5]	80	12	--	85	
	H [2000-120-1.5]	80	16	--	75	-
h/b ratios	C [500-120-1.5-100]	80	4	1:100	175	**1.45**
	C [1000-120-1.5-100]	80	8	1:100	160	**1.65**
	C [1500-120-1.5-100]	80	12	1:100	142	**1.67**
	C [2000-120-1.5-100]	80	16	1:100	130	**1.73**

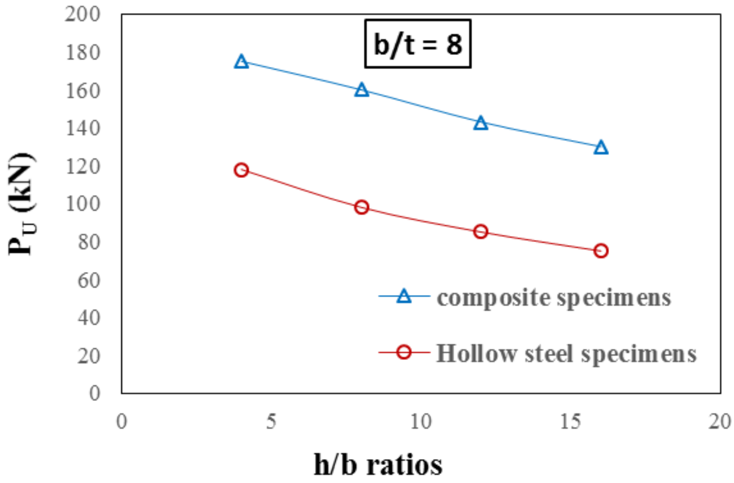

Fig 9. Relationship between h/b ratios and P_U

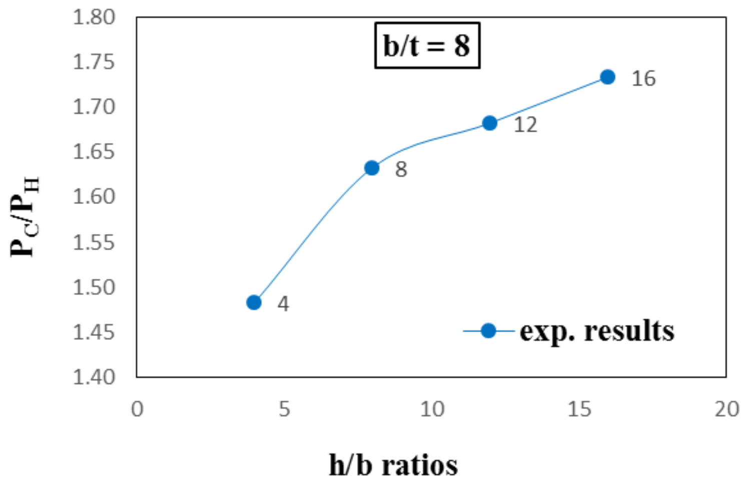

Fig 10. Relationship between h/b ratios and P_C/P_H

Effect of Height-to- Width Ratio (h/b) on Load-Shortening (P-Δ) Curve

In this section, the effect of using different h/b ratios (4, 8, 12, and 16) on the shortening of columns is studied. P- Δ curve for specimens C [500-120-1-100], C [1000-120-1.5-100], C [1500-120-3-100], and C [2000-120-2.5-100] are shown in Figure 21. Results of all specimens are tabulated in table 4.Figureshows the relation between applied load and the shortening of specimens measured manually from dial gauge (1).

Figure 11 clear that the load-shortening relationship for composite sections is more nonlinear with h / b ratios decreased. The shortening values for the composite column specimens at the same load are 1.4, 1.7, 2.5 and 3.4 mm for specimens with h / b = 4, 8, 12, and 16 respectively. Composite columns stiffness decreases with h/b ratio increase. Because when using a large composite column height with a small width, general buckling occurs, which reduces the axial shortening stiffness thus the sand -epoxy core is formed and the section is formed then the axial shortening occurs. P- Δ curve is linear under initial loading with a slope depending on the specimen stiffness, then the shortening rate increases and the relationship takes a form of a parabolic curve until reaching the ultimate load. The decrease of the specimen stiffness which takes place before reaching the ultimate load is a result of the weakness of the slender steel tube.

Table 4. Axial shortening (Δ_y) results of test specimens

parameter	**Specimens**	**b/t**	**h/b**	**Mix Ratio**	**P_U (kN)**	**Δ_y (mm)**
	H [500-120-1.5]	80	4	--	118	**1.1**
	H [1000-120-1.5]	80	8	--	98	**1.8**
	H [1500-120-1.5]	80	12	--	85	**2.5**
	H [2000-120-1.5]	80	16	--	75	**2.9**
	C [500-120-1.5-100]	80	4	1:100	175	**2.3**
	C [1000-120-1.5-100]	80	8	1:100	160	**2.5**
h/b ratios	C [1500-120-1.5-100]	80	12	1:100	142	**3**
	C [2000-120-1.5-100]	80	16	1:100	130	**3.4**

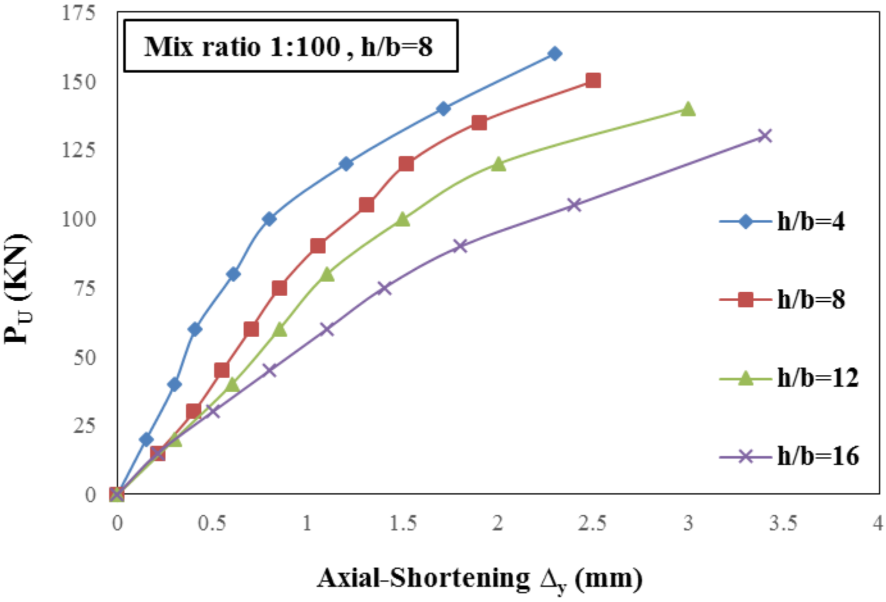

Fig 11. Axial displacement versus load applied for all specimens of composite columns

Conclusions

Based on the experimental works of both the composite columns and hollow steel columns, the following conclusions are drawn:

1. Sand and epoxy resin mix filled hollow steel columns have given a range of advantages, including speed of construction, lightweight, high adhesion, low shrinkage, high tensile strength, high ductility.
2. The relationship between stress and strain for the sand and epoxy resin mix is linear. The stress increases linearly with the increase of the strain in the elastic zone and terminates when the material break.
3. The fracture occurred by the convex local buckling of the steel section due to the outward thrust of the filling material.
4. The crushing of the filling material (sand and epoxy resin mix) is observed at the same location as the local buckling of the steel tube. When the steel tube buckles outward, a gap between the steel tube and filling material exists at these locations.
5. Sand and epoxy resin mix increases column strength signification.
6. The specimens with higher h/b have gained strength more than specimens with low h/b. That's because the failure of specimens with high h/b is controlled by global buckling. Presence of sand-epoxy resin core results in the delay of global buckling occurrence.
7. The sand and epoxy resin mix have a great effect on the behavior of axial displacement for composite sections this is indicated that the composite sections have more stiffened than the hollow steel section.
8. Composite columns stiffness decreases with h/b ratio increase.

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