Performance of blended cement SCC filled steel tubes for repair/rehabilitation of structural columns of buildings, bridges and deep foundations

T. Kibriya & M. Iqbal
National University of Sciences and Technology, Pakistan

Abstract

Research on structural performance of confined self-consolidating concrete tubes as columns is scarce and there is little data available. Similarly, there is little research on use of blended cement containing agricultural waste, i.e. rice husk ash as cementitious material in normal/high strength concrete. Limited research has shown better performance of such blended cements with increased strength by up to 30% and improved durability, reduced permeability and shrinkage. Its behaviour under confined conditions is still to be studied. This paper provides valuable research in this area with special focus on the use of blended cement SCC confined in steel tubes applicable for rehabilitation/replacement of columns of old bridges and buildings as well as in deep foundation applications. This paper presents an experimental study on the behaviour of short, SCC, with blended cement containing 75% ordinary Portland cement and 25% rice husk ash, filled steel tubular columns axially loaded in compression to failure and compares the results with testing on similar hollow tubes and tubes filled with normal concrete. Almost 350 to 460% increase in strength was observed by filling steel tubes with SCC (containing blended cement) in square and circular tubes respectively. Failure strains were also reduced by 40 to 45%. Smaller steel sections and use of blended cement containing rice husk ash reduces the costs of repairs/renovation works along with reducing the disposal problems of this massively produced agricultural waste in the rice growing regions.
Keywords: blended cement, rice husk ash, concrete filled steel tubes, repair/rehabilitation works.

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1 Introduction

Both the compressive strength of concrete and the integrity of the concrete cross-section within the confined steel tube depend on the efficient consolidation of fresh concrete during placement achieved through vibration. In deep and smaller concrete sections with limited accessibility, consolidation of concrete is particularly difficult. Over-consolidated concrete might segregate whilst under-consolidated concrete can have voids and cavities. Consequently, the integrity and uniformity of the concrete cross-section is not assured, adversely affecting the strength. Self-consolidating concrete (SCC) consolidates under its own weight with no vibration and without exhibiting segregation or bleeding assures the structural integrity and uniformity of the cross-sectional area of such deep sections. Recent research on use of blended cement containing agricultural waste i.e. rice husk ash has proved to increase compressive strengths of normal/high strength concretes by about 30% along with reducing the permeability, shrinkage and improving durability of such concrete to acid, sulphate and chloride attack by Kibriya et al [1–4]. Selection of 25% replacement of OPC with rice husk ash has been on the basis of excellent performance of such blended cements and concrete in the recent studies by Kibriya [1, 5, 6].

The steel tube in a concrete filled steel column acts as longitudinal and lateral reinforcement subjected to longitudinal compression and hoop tension, whilst the concrete is stressed tri-axially. The advantages of the concrete filled steel tube columns over other composite systems are that the steel tube provides reinforcement, formwork for concrete, prevents concrete spalling, environmental damage and from offensive agencies whilst concrete in the steel tube supports thin walls and prolongs/prevents local buckling of the steel tubing. The composite column adds significant stiffness to the structure as compared to more traditional steel frame.

2 Research significance

This study carries significance due to the absence of any worthwhile research on confined SCC along with the use of environmentally friendly agricultural waste i.e. rice husk ash used for blending in cement. Advancements in the availability of better steels, effective coating materials for steel protection and high performance concretes have expanded the scope of concrete filled steel composite columns with wide ranging applications in various structural systems with ease of construction, highly increased strengths and better performance. Such columns can easily and economically be used in repair/replacement works in old buildings, bridges and deep foundation strengthening.

3 Research methodology

A total of 20 series with 60 specimen in four groups comprising two groups of circular shape and two square shapes were tested. 3 specimen in each group were hollow, 3 filled with normal concrete, 3 filled with SCC with blended cement,

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3 braced and filled with normal concrete and 3 braced and filled with SCC containing blended cement. Braced tubes were hollow steel tubes cross braced internally with #3 deformed bars welded in transverse direction, alternately at a distance of 150mm centre to centre and filled with concrete. The height of all specimen was 750mm. A super plasticising admixture along with a viscosity modifying agent were used in preparing SCC with blended cement.

Table 1: Geometric properties of steel tubes used.

Group	Column Type	Outer Dia mm	Inner Dia mm	Thickness mm	D/t or b/t	L/D or L/b	λ
A	Circular	160	155	2.5	64	4.69	19
B	Circular	111.25	106.25	2.5	44.5	6.74	27
C	Square	125.66	120.66	2.5	50.26	5.97	21
D	Square	87.38	82.38	2.5	34.95	8.58	30

Λ – slenderness ratio, D – dia, t – thickness, b – width, L – length.

Figure 1: Photographs showing failure modes and test setup of columns.

The dimensions of the square columns selected aimed at maintaining similar cross sectional area as of corresponding circular columns. Hence square columns of Group C have similar cross sectional area as of circular columns of Group A and similarly Group D have similar cross sectional area as of circular columns of Group B. Other details are given in Table 1. Steel Pipes used for this experimental investigation were made of 250MPa steel. Geometry is shown in Figure 1. Ordinary Portland cement was used with crushed granite coarse aggregates and medium grading sand for normal concrete. 75% ordinary Portland cement blended with 25% rice husk ash was used as cementitious material for SCC. Concrete strengths of 30Mpa were used as shown in Table 2. Rice husk ash used for blending was obtained by burning rice husk in an industrial furnace with temperatures maintained around 500 to 600^{0}C. Ashes were then cooled to 20^{0}C and subsequently ground in a laboratory ball mill for about 120 minutes and thereafter sieved through a #325 sieve. Ashes passing

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100% through the sieve were then used for blending with ordinary Portland cement. The test strengths of different columns were also compared with strengths given by various codes and also the design equation proposed by Giakoumelis and Lam [7].

Table 2: Properties of concrete used.

Ser	Sample	Slump mm	$f_c^/$ (Mpa) 28 days	$f_c^/$ (MPa) 90 days
1	Normal Concrete	60	31	37
2	SCC with bended cement	610	36	45.7

Table 3: Proportions of concrete used.

Type	W/C Ratio	Cement Kg/m^3	Water	Sand Kg/m^3	Gravel Kg/m^3	VMA	SP
Normal Concrete	0.45	360	162	710	1040		
SCC with blended cement	0.45	380	171	860	860	0.02 %	3l/ m^3

Table 4: Limiting values of b/t.

Type	LRFD	Eurocode	ACI code
Square	40	50.6	49.16
Circular	40	85	80

4 Code check for minimum thickness requirement – steel tube

Minimum b/t requirements under LRFD, Eurocode and ACI are given in Table 3. The minimum steel requirement is given in Table 4 confirming that all columns have steel area more than 4%.

5 Testing procedure

The columns were tested in a 2000 kN capacity Universal compression testing machine. The specimens were centered in the testing machine in order to avoid eccentricity. Loading rate was maintained at 4.5kN/s. vertical displacement was measured by displacement transducers. The top and bottom faces of specimen were grinded and made smooth and leveled to remove surface imperfections and maintain uniformity of loading on the surface.

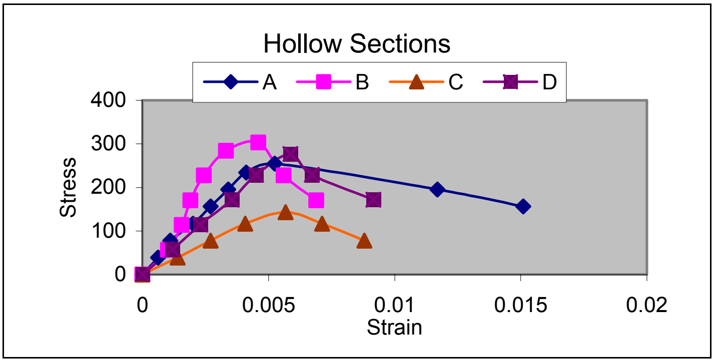
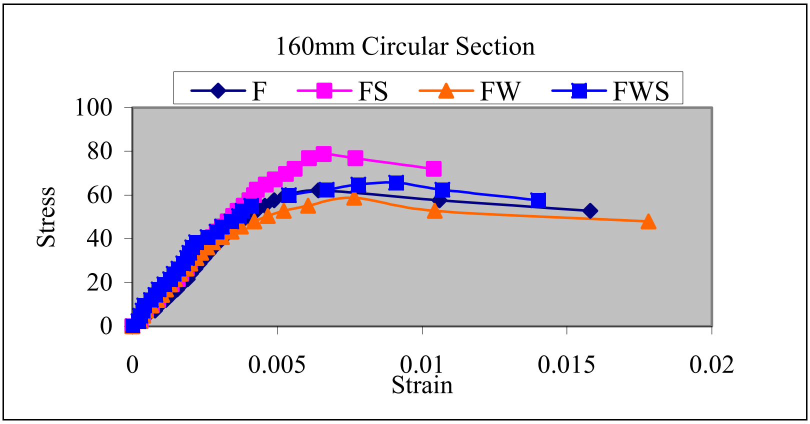


Figure 2: Stress – strain curve of hollow columns.



Note:-F- Filled, S – SCC with blended cement, W - Braced

Figure 3: Stress – strain curve of 160mm circular columns.

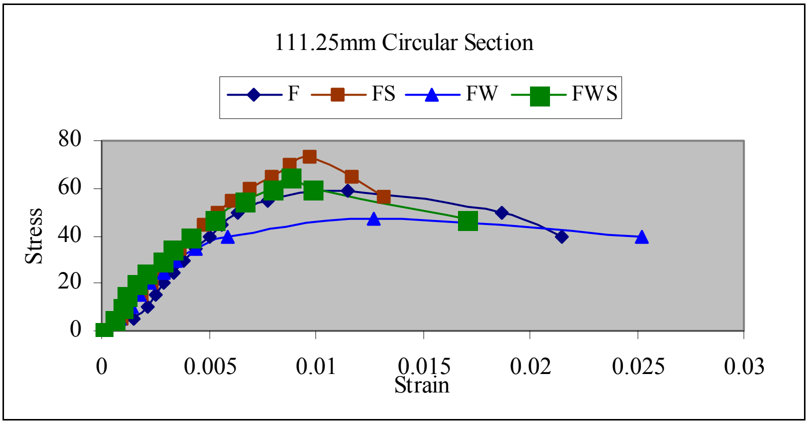


Figure 4: Stress – strain curve of 111.25mm circular columns.

6 Experimental results

The stress–strain behaviour of specimen tested is shown in Figures 2 to 6. The test results are listed at Table 6. Most results observed for normal concrete filled steel tubes are compatible with the recent research carried out by Han et al [8], O'Shea [9], Knowls and Park [10], Kibriya [11] and Chalib [12].

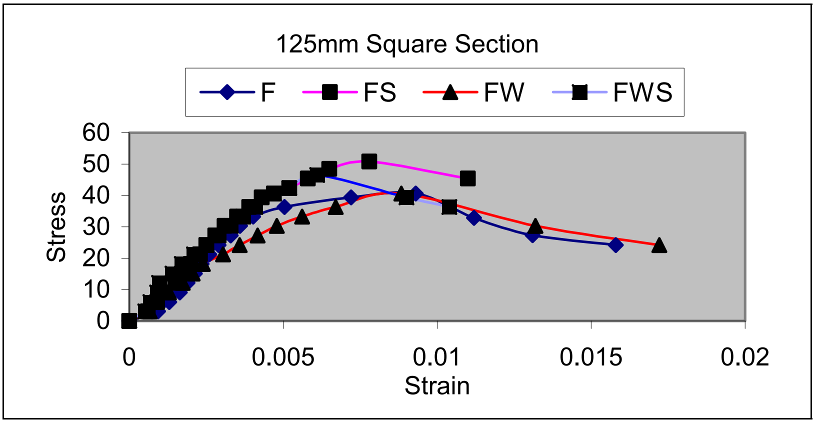


Figure 5: Stress – strain curve of 125mm square columns.

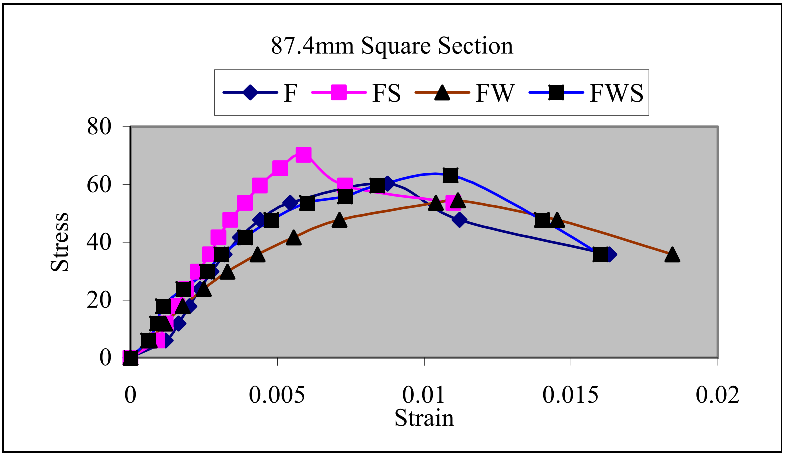


Figure 6: Stress – strain curve of 87.4mm square columns.

6.1 Hollow steel columns

All columns behaved in almost similar way with yielding strain observed to be between 0.004 and 0.006 and stress in steel around 250MPa at failure. Deformation behavior was also similar. Square columns started yielding at lower

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Table 5: Results of experimental testing and comparison with codes.

Ser	Column type	Actual capacity kN	Pu LRFD kN	Pu ACI kN	Pu Eurocode kN	Georgios Equation kN
1	A circular hollow	290	341	341	309.25	309.25
2	-do- filled NC	1296	698	784	909	986.27
3	-do- filled & braced NC	1025	698	784	909	986.27
4	-do- filled SCC	1640	698	784	909	986.27
5	-do- filled & braced SCC	1370	698	784	909	986.27
6	B circular hollow	237	235	235	213.50	213.50
7	-do- filled NC	591	380	443	454	531.61
8	-do- filled & braced NC	474	380	443	454	531.61
9	-do- filled SCC	722	380	443	454	531.61
10	-do- filled & braced SCC	647	380	443	454	531.61
11	C Square hollow	183	339	339	307.75	307.75
12	-do- filled NC	670	551	681	788	830.13
13	-do- filled & braced NC	595	551	681	788	830.13
14	-do- filled SCC	840	551	681	788	830.13
15	-do- filled & braced SCC	765	551	681	788	830.13
16	D Square hollow	241	234	234	212	212
17	-do- filled NC	505	293	393	428	455.48
18	-do- filled & braced NC	497	293	393	428	455.48
19	-do- filled SCC	594	293	393	428	455.48
20	-do- filled & braced SCC	565	293	393	428	455.48

NC – Normal concrete, SCC – Self compacting concrete with blended cement.

loads as compared to circular ones. Figure 2 shows the stress-s
hollow columns.

6.2 Concrete filled columns

6.2.1 160mm dia circular columns

About 460% increased strengths were observed for circular columns filled with SCC with blended cement. Columns filled with normal concrete showed increased strengths by about 300% as compared to the load carrying capacity of hollow steel columns. Failure strains were observed to be in the range of 0.006 to 0.007. The stress strain curve indicates ductile behaviour as shown in Figure 3.

6.2.2 111.25mm dia circular columns

About 200% increased strengths were observed for circular columns filled with SCC with blended cement whilst similar tubes filled with normal concrete were observed to have increased strengths by about 150%. Failure strains in both cases were observed to be in the range of 0.009 to 0.01. The shape of the stress strain curve indicates extremely ductile behaviour as shown in Figure 4.

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6.2.3 125mm square columns

360% higher strengths were observed for square columns filled with SCC with blended cement whilst similar tubes filled with normal concrete were observed to have increased strengths by about 260%. Failure strains were observed to be in the range of 0.007 to 0.008. Stress strain curves are shown in Figure 5.

6.2.4 87.4mm square columns

146% higher strengths were observed for square columns filled with SCC with blended cement whilst similar tubes filled with normal concrete were observed to have increased strengths by about 100%. Failure strains were observed to be in the range of 0.01. Stress strain curves are shown in Figure 6.

6.3 Concrete filled braced columns

6.3.1 160mm dia circular columns

About 360% increased strengths were observed for circular columns filled with SCC with blended cement as compared to 250% increased strength for columns filled with normal concrete. Failure strains in both cases were observed to be in the range of 0.006 to 0.007 with ductile behaviour as shown in Figure 3.

6.3.2 111.25mm dia circular columns

About 170% increased strengths were observed for circular columns filled with SCC with blended cement whilst similar tubes filled with normal concrete were observed to have increased strengths by about 95%. Failure strains in both cases were observed to be in the range of 0.009 to 0.01 with extremely ductile behaviour as shown in Figure 4.

6.3.3 125mm square columns

310% higher strengths were observed for square columns filled with SCC with blended cement whilst similar tubes filled with normal concrete were observed to have increased strengths by about 225%. Failure strains were observed to be in the range of 0.007 to 0.008. Stress strain curves are shown in Figure 5.

6.3.4 87.4mm square columns

134% higher strengths were observed for square columns filled with SCC with blended cement whilst similar tubes filled with normal concrete were observed to have increased strengths by about 100% as compared to the load carrying capacity of hollow steel columns. Failure strains were observed to be in the range of 0.01. Stress strain curves are shown in Figure 6.

6.4 Failure modes

Almost all columns failed due to local buckling of steel followed by crushing of concrete. The failure was a ductile one. The failure mode of almost all columns was due to steel plate buckling along with typical crushing failure of concrete where the steel wall was pushed out by the concrete core, which was confined by the steel as shown in Figure 2. When the steel was removed from the specimen after failure, the concrete was found to have taken the shape of the deformed steel tube, which illustrates the composite action of the section.

6.5 Effect of concrete area and confinement

For concrete filled circular sections, the confinement effect of concrete increases the concrete strength. Due to concrete confinement the stress bearing capacity of concrete increased 3.5 to 4.5 times in circular columns. It implies that when diameter is kept constant and steel thickness is increased, the confinement factor increases thereby increasing the compressive strength of concrete as observed by Giakoumetic and Lam [7] Knowls and Park [10] and Kibriya [11]. It has also been observed that for circular sections, increase in concrete area increased the strength of the column.

7 Strength comparison by design codes

The values calculated by method given in various codes are listed at Table 6. It can be observed that all codes give conservative values whereas capacities calculated by using proposed equation by Giakoumelis and Lam [7] are more realistic for normal concrete filled circular columns. For square tubes, this equation gives reasonable values for smaller sections but give excessively large values for larger sections. The proposed equation is: $N_u = 1.3 A_c f_c^/ + A_s f_s$. SCC with blended cement filled in tubes gives 60 to 65% higher strengths.

8 Conclusion

SCC with blended cement increased the load carrying capacity of hollow steel columns by 350 to 460% for square and circular columns respectively. The failure strains observed for SCC with blended cement filled columns were similar to the failure strains observed for tubes with normal concrete thereby indicating the reduced strains for SCC with blended cement filled specimen due to higher loads. Almost 100 to 150% increased load carrying capacity was observed for SCC with blended cement filled steel tubes as compared to similar steel tubes filled with normal concrete. Circular sections with larger concrete area showed higher increase in strength and reduced strains as compared to smaller section with lesser concrete area and square sections. Such higher strengths of SCC with blended cement filled steel tubes implies use of smaller sections in repair/renovation works. Use of efficient smaller sections along with cheaper rice husk ash blended in cement for self compacting concrete reduces the cost resulting into cheaper and economical cost of repairs and rehabilitation works.

References

[1] Kibriya. T. and Baig. N., High performance concrete with blended cements using agrowastes, Proceedings of McMat 2005, Joint

ASCE/ASME/SES Conference on mechanics and materials, Baton Rouge, Louisiana, USA, 2005.
[2] Kibriya. T. and Khan. S., High performance concrete pavements using agrowaste blended cement, Proceedings of McMat 2005, Joint ASCE/ASME/SES Conference on mechanics and materials, Baton Rouge, Louisiana, USA, 2005.
[3] Kibriya. T. and Khan. S., Performance of ecologically friendly waste in high strength concrete, IV Regional Conference on Civil Engineering Technology, Joint ASCE/ESIE Conference, Cairo, Egypt, 2005.
[4] Kibriya. T. and Baig. N., Agricultural wastes in construction, Blended cements containing rice straw ash, IV Regional Conference on Civil Engineering Technology, Joint ASCE/ESIE Conference, Cairo, Egypt, 2005.
[5] Kibriya. T., Ferrocement as retrofit material for old structures, Proceedings of McMat 2005, Joint ASCE/ASME/SES Conference on mechanics and materials, Baton Rouge, Louisiana, USA, 2005.
[6] Kibriya. T., Ferrocement – An innovative material for rehabilitation/ strengthening of brick masonry columns, IV Regional Conference on Civil Engineering Technology, Joint ASCE/ESIE Conference, Cairo, Egypt, 2005.
[7] Giakoumelis G. and Lam. D., Axial capacity of circular concrete-filled tube columns, Journal of Constructional Steel Research 60 (2004) 1049–1068
[8] Han. L.H., Tao. Z. and Liu. W., Effects of Sustained Load on Concrete-Filled Hollow Structural Steel Columns, Journal of Structural Engineering, ASCE, September 2004)
[9] O'Shea. M. D., Design of Circular Thin-Walled Concrete Filled Steel Tubes. Journal of Structural Engineering, ASCE, November 2000.
[10] Knowls. R. B., Park. R. Strength of concrete filled steel tubular columns. ASCE, J Struct Div 1969;95(ST12):2565–87.
[11] Kibriya. T., Performance of concrete filled steel tubes under uni-axial compression, IV Regional Conference on Civil Engineering Technology, Joint ASCE/ESIE Conference, Cairo, Egypt, 2005.