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State of the art report on steel-concrete infilled composite column

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ABSTRACT

Steel-concrete composite systems for buildings are composed of concrete components that interact with structural steel components within the same system. By their integral behavior, these components give the required attributes of strength, stiffness and stability to the overall system. Composite members, as individual elements of a system, have been in use for a considerable number of years. In this paper, a review of the research carried out on composite columns with infills is given with emphasis on experimental work.

Introduction

Composite columns may be practically used for low and high-rise buildings. For the low-rise buildings, steel columns are often encased in concrete for the sake of appearance or for protection of steel from fire, corrosion, and from vehicle in garages. For high-rise buildings, composite columns are stiffer than non composite steel columns. The size of composite columns is often considerably smaller than is required for reinforced concrete columns to support the same loads. The high tensile strength and ductility are the main advantages of steel members. They can also be used for erection of the building and resisting all construction loads. However, concrete members can increase the compressive strength and stiffness to assist the resistance of service loads. The choice of a steel, concrete, or composite system for any particular project depends not only on system efficiency, material availability, cost, construction methods, and labour, but also on planning, architectural, and aesthetic criteria. It is thus impossible to reach definitive conclusions solely on the basis of a structural system evaluation.

Composite Column

A type of column that incorporates two materials or elements of design in its structure is a composite column. A composite column in other words, is a column that includes a steel core surrounded by concrete. The concrete may either be solidly filled in around the steel section or may simply encase the steel inside a hollow space, reinforced by other internal support. These structures are intended to be load-bearing and have many advantages over plain steel or concrete. The term composite column, as applied in architecture, may refer to a column of the Composite order. The steel backbone of a composite column lends its increased strength and resistance to buckling.

Composite columns are of two types:

(1) Concrete encased structural steel shapes
(2) Concrete filled tubular steel sections

Concrete encased steel columns

They are commonly used. The concrete encasement has often been considered as only fire and corrosion protection for the steel. However, in recent years, lateral and sometimes longitudinal reinforcement has been added to the concrete encasement, and the resultant strength of the steel and concrete interacting has been used for structural purposes. A steel shape, encased in concrete, may be thought of as reinforcement for the concrete.

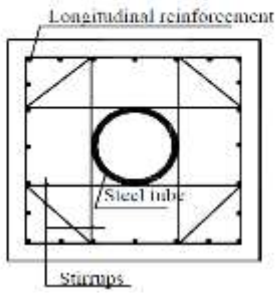

Fig.1 Encased composite column

Concrete-filled tubular steel columns

They have been popular for use as individual column elements. The confined concrete fill increases the axial load resistance but has little effect on the flexural resistance. For that reason, it is unlikely that these columns would be a good choice for a moment resisting frame. Filling the tube with concrete will increase the ultimate strength of the member without significant increase in cost. The main effect of concrete is that it delays the local buckling of the tube wall and the concrete itself, in the restrained state, is able to sustain higher stresses and strains than when in the unrestrained state.

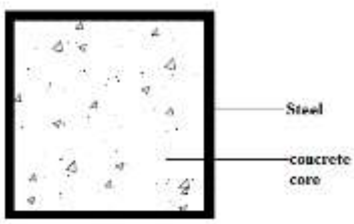

Fig.2 Concrete filled steel column

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Advantages of using concrete filled tubular columns

The use of concrete filled tubular columns provides large saving in cost by increasing the floor area by a reduction in the required cross-section size. This is very important in the design of tall buildings in cities where the cost of letting spaces are extremely high. Concrete filled tubular columns can provide an excellent monotonic and seismic resistance in two orthogonal directions. Using multiples bays of composite concrete filled tubular column framing in each primary direction of a low-to medium-rise building provides seismic redundancy while taking full advantage of the two-way framing capabilities of concrete filled tubular columns. As a typical composite structural system, due to the composite effects, the advantages of the two materials can be utilized and their disadvantages can be avoided, thus forming a more rational system. The steel tubes can be used as the formwork for casting concrete and the shoring system in construction, thus concrete filled tubular column structures have much better constructability than concrete structures.

Composite action between structural elements

Composite action between the various structural elements in a structure always exists when they are continuous. Depending on the size of the building, certain simplifications may be made to approximate their interaction, as isolated structural components, in a conservative manner. The use of higher strength materials and composite action are important factors in making entire systems work economically. Tall buildings require additional considerations such as slenderness, flexibility, and sensitivity to differential effects. Steel and concrete are the major materials used in composite systems. Although they have several dissimilar physical characteristics, it is possible to use them together, beneficially, in different ways. A number of systems have been developed in the last few decades which successfully combine steel and concrete.

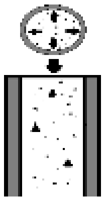

Fig 3 Composite action between structural elements

Seismic behaviour of concrete filled tubular columns

The seismic behavior of concrete filled tubular columns under cyclic loading is good. *Xilin Lu and Weidong Lu* in their paper presented the seismic behavior of concrete filled rectangular tubular columns. An investigation of the seismic behavior of 12 concrete filled rectangular tubular column specimens subjected to reversed cyclic loading and constant axial load is reported in the paper. The specimen was supported by cylinder hinged support at top and bottom ends. Axial load was first applied to the bottom of the specimen using a 3200 kN hydraulic jack operated in load control. Lateral load was then applied in the middle of the specimen using a 500 kN servo-controlled hydraulic actuator operated in load control, before yield of the steel plate and in displacement control after the yield. The behaviour of the specimens was monitored during testing by load cell, LVDT, and electrical resistance foil strain gages. All data was recorded intermittently on a personal computer. The concrete filled rectangular tubular columns exhibited better behavior of resisting local buckling when compared to steel tubular columns without infill. The effects of varying width-thickness ratio of the steel plate, axial compression ratio, and different strengths of in filled concrete had an impact on the seismic behavior of concrete filled rectangular tubular columns. When compared to conventionally reinforced concrete columns the concrete filled rectangular tubular columns exhibited greater energy-dissipation characteristics. The test results showed that the use of a thicker steel tube can increase the strength. Higher concrete strength will result in higher ultimate strength but larger strength degradation and lower energy dissipation compared to columns with normal strength concrete. It was also found that higher axial compression force resulted in low energy dissipation and larger strength degradation.

Behaviour of Fibre reinforced and rubber concrete filled tubular columns

The use of fibre reinforced concrete and rubber concrete result in considerable improvement in the structural behaviour of slender composite columns subjected to axial loading. *E.K.Mohanraj, Dr.S. Kandasamy* determined the experimental behavior of axially loaded slender hollow steel columns in-filled with fibre reinforced and rubber concrete. The specimens were tested under axial compression to investigate the effects of fibre reinforced and rubber concrete on the strength and behavior of slender composite columns. The slenderness ratio (L/D) in was taken as 12. The average values of yield strength and ultimate tensile strength for the steel tube were found to be 260 and 320 MPa respectively. All of the tests were carried out in an Electronic Universal Testing Machine with a capacity of 1000 kN. The columns were hinged at both ends and axial compressive load applied. A small pre-load of about 5 kN was applied to hold the specimen upright. Dial gauges were used to measure the lateral deflections of the columns at mid height. The load was applied in small increments of 20 kN. At each load increment, the deflection measurements were recorded. All specimens were loaded to failure. The ductility was found to be almost equal for both plain and FRC filled steel tubular columns and high for rubber concrete. The use of fibre reinforced and rubber concrete in the steel tube, results in an enhanced energy absorption capacity of the composite columns. The use of fibre reinforced and rubber concrete as a filling material increased the load bearing capacity to a much greater extent compared with that of unfilled columns and reduced the lateral deflection.

Behaviour of lightweight concrete filled tubular column

The steel tubes filled with lightweight aggregate concrete show acceptable strength under the applied load. *Shehdeh Ghannam* compared the load carrying capacity of light weight aggregate concrete filled steel tubular columns with normal weight aggregate concrete filled steel tubular columns both experimentally and theoretically. Theoretically, the squash loads, Nu, (According to the Bridge Code) were calculated using the formulae.

$$Nu = As\, fsk / \gamma ms + Ac\, fck / \gamma mc \qquad -(1)$$

The material partial safety factors for steel and concrete γms *, and* γmc *were* taken as unity. Moreover, the value of the characteristic concrete strength *fck* was taken as $fck = 0.83\ fcu$ instead of $fck = 0.67\ fcu$, where *fcu* is the 28 day cube strength of concrete . The value of $0.83\ fcu$ is considered from the experimental work. Furthermore, the ratio between $Ac\, fck/ \gamma mc$ and *Nu* is called the concrete contribution factor αc, and for a filled composite section it may vary between 0.1 and 0.8. The *fsk* value is taken as $fsk = 0.91\ fy$. Experimentally two different concrete mixes were used with a max. aggregate size of 10mm.For normal concrete , a concrete mix of 1 : 1.4 : 2.8 / with w/c=0.6 (Ordinary Portland cement ,medium crushed limestone aggregate gravel and fine sand (2mm size)) were used. For lightweight concrete , pumice of 10mm size was used with expanded perlite in the ratio 1 : 1.53, exp. perlite 0.92 L/Kg of pumice with w/c = 0.85.The column specimens were tested under axial monotonic loading in a 2000 KN capacity compression hydraulic jack (M 1000/RD) , with a deformation rate of 0.01mm/sec. All specimens were prepared and placed axially under the applied load with a high degree of accuracy to ensure the load application to the required position .All columns were tested up to failure to assess their behavior. Sections filled with lightweight aggregate concrete failed due to local as well as overall buckling, and they were capable of supporting more than 92% of the load. Sections filled with normal weight aggregate concrete failed due to overall buckling at mid height, and they were capable of supporting more than 87% of the load. It can obviously be seen that normal concrete-filled steel tubular columns support 1.24 times higher loads than those filled with lightweight aggregate concrete. On the other hand, the weight of the column with lightweight concrete was 20% to 26%lighter than that of the column with normal concrete of the same cross section. Column specimens filled with lightweight aggregate concrete developed the ultimate axial capacity and significantly enhance the strength of the steel sections. The load carrying capacity of the column is increased by view of the fact that the concrete core, in addition to its own strength contribution, also helps to prevent the effect of local buckling of the steel tube. This increases the strength contribution of the tube portion over the hollow section.

Behaviour of short length steel tubular

Slender concrete filled steel tubular columns tend to exhibit less increase of load due to confinement effect since they fail due to overall buckling. Circular concrete filled steel tubular section has additional strength compared to square section due to confinement of concrete. This depends on diameter-to-thickness ratio, and the slenderness of the member. *Narayanan S.P et al* studied the behavior of short length steel tubular columns. Short Steel tubular members Circular Hollow Sections CHS30 and CHS50 were infilled with concrete of grade 30, 60 and 80MPa and grout and tested in axial compression. The slenderness was kept below limiting values for short columns, namely 50. The experimental values were compared with ultimate strength predictions of codes EC4, BS5400, ACI, AS and AIJ .Steel tubulars of intermediate length, with slenderness in between 50 and 200, and length 1200 mm infilled with concrete of grades 30, 60 and 80 MPa were tested in axial compression and compared with code predicted ultimate strengths using EC4, BS5400, ACI, AS and AIJ. External diameter-to-plate thickness (D/t) ratios ranged from 11 to 14. Rehabilitation of artificially damaged tubulars using concrete and grout. The artificial damage simulated patch type corrosion commonly seen in offshore tubulars. The artificial damage is obtained by grinding an area of the surface to a specific width, height and reduced wall thickness. The specimens were tested in axial compression. The predicted strength of concrete filled steel tubular was 5% higher than the experimental results when concrete infill of 60MPa and 80MPa was used. Although, the diameter-to-thickness ratios are low (11 and 14), the confinement of concrete had less effect on the specimens because the experimental result had lower values than the predicted by the EC4 that takes consideration of confinement. Overall, the behaviour of the high strength concrete filled steel tubular intermediate length columns is characterized by elastic buckling, and although there is no confinement, the strength of concrete adds compression capacity of the column. Comparison between the code prediction (EC4) for concrete filled steel tubular and experimental strength of the concrete-filled corroded steel tubes shows that the strength of concrete-filled steel tubes were reduced by 40-50% due to the corrosion. This indicates that strength reduction due to corrosion is a major problem for concrete-filled column. The rehabilitation methods used showed a significant increase of strength for the damaged steel tubes.

Bond stress characteristic

Bond strength and compressive strength of concrete filled tubular columns can be improved by adding fly ash. Light weight aggregate concrete offer higher bond strength and compressive strength than normal concrete. Use of metakaoline to the concrete of concrete filled tubular columns improves the bond strength and compressive strength of the concrete. It was experimentally investigated by *Radhika and Baskar*. Mix proportion of cement, sand, aggregates of 1:2:2.37 and a water cement ratio of 0.4 were used. For each mix standard cube tests were used to determine the compressive strength of the concrete. A total of 30 cubes were prepared by adding different percentage of metakaoline in concrete and tested on a compression testing machine of 2000kN capacity after 7 days and 28 days of curing. Each tubular specimen was tack welded by a mild steel flat with a thickness of 6mm and with width of 10mm. After that concrete mix was filled in multiple layers for all specimens and was vibrated by a vibrator machine. These specimens were then naturally cured in the indoor climate of laboratory. Prior to testing, the top surfaces of the concrete filled steel tube columns were smoothened in order to avoid the eccentricity of loading. The columns were tested as pin-ended supported and subjected to axial loading. Load was applied through edges of each specimen to the concrete only. All experiments were done in 100T capacity loading frame machine. To measure the applied load, a strain gauge base load cell was used and to measure the axial displacement (slip), two linearly variable displacement transducer (LVDT) was placed diametrically opposite to each other. All data was scanned every second and the data is stored using AI-8000+ 16 channel data logger with a help of computer. Also at required point of loading a separate tag file is stored for analysis of data with a help of PRO-sof software. Equation is used for finding out the bond stress of all specimens from their failure load fb=P/ (DL). Bond strength increases with increasing in length to diameter ratio of the steel tube. The compression strength of the concrete core for all specimens with metakaoline varies from 50 to 75Mpa. The bond strength of metakaoline concrete filled tubular column specimens obviously increases with the increase of the compression strength of the specimen, adding mineral admixtures like metakaoline to the concrete is effective in increasing the member ductility and also effective in ultimate strength of the concrete filled tubular column columns. It was observed that the bond carrying capacity decreases with increasing percentage of metakaoline but increases up to 15% of metakaoline in concrete. Compression strength of the concrete core is other important parameter to affect the bond strength of metakaoline concrete filled tubular column specimens. The results from push out tests in this experiment indicate that bond strength of metakaoline concrete filled tubular columns specimens is greater than that of concrete filled tubular columns specimens.

Table 1. Test results

No.	Specimen	D (m)	t (mm)	fcu (MPa)	fy (MPa)	N/N0	N (kN)	Qul (kN)	Qur (kN)	Xy (mm)	Xu (mm)	μ
1	R3M5	200	3.030	44.9	283.4	0.5	950	-292.9	280.4	3.52	17.01	4.83
2	R3M7	200	3.041	44.9	283.4	0.7	1350	-230.4	238.9	2.98	8.63	2.90
3	R5M5	200	4.908	44.9	314.1	0.5	1200	-353.1	375.3	3.52	15.27	4.34
4	R5M7	200	4.955	44.9	314.1	0.7	1680	-340.5	321.7	3.01	9.66	3.21
5	R4L5	200	4.054	39.5	311.0	0.5	1050	-316.8	313.1	2.83	--•	--
6	R4L7	200	4.068	39.5	311.0	0.7	1450	-284.5	305.1	3.32	10.14	3.05
7	R4H5	200	4.075	48.1	311.0	0.5	1150	-385.8	366.8	2.39	12.37	5.17
8	R4H7	200	4.074	48.1	311.0	0.7	1600	-346.6	337.1	3.17	12.10	3.82
9	R4M3	200	4.073	44.9	311.0	0.3	650	-283.6	305.2	3.05	22.99	7.54
10	R4M5	200	4.071	44.9	311.0	0.5	1100	-309.7	321.0	2.96	15.09	5.10
11	R4M7	200	4.066	44.9	311.0	0.7	1550	-250.2	277.8	3.52	9.71	2.76
12	R4M5m	200	4.078	44.9	311.0	0.5	1100	-	349.7	5.73	43.70	7.63

Table 2. Details of the specimens used

Column Type	Section Dimensions(mm)	Effective Length (mm)	Slenderness Ratio
C1-N	200x100x5	2000	20
C2-N	200x100x5	2000	20
C3-LW	200x100x5	2000	20
C4-LW	200x100x5	2000	20
C5-N	150x90x3	2250	25
C6-N	150x90x3	2250	25
C7-LW	150x90x3	2250	25
C8-LW	150x90x3	2250	25

Table 3. Test Results

Col. No. & type	Concrete contribution factor (α_c) Bridge Code	Squash Load N_u (KN) Bridge Code	Experimental Failure Load N_e (KN)
C1-N	0.303	1356	1242
C2-N	0.333	1417	1242
C3-LW	0.139	1103	1062
C4-LW	0.116	1048	1022
C5-N	0.448	736	691
C6-N	0.442	728	638
C7-LW	0.200	511	503
C8-LW	0.164	489	491

Table 4 Comparison of test compression strength with code strength

Sample No	N_{Exp} kN	N_{EC4}		N_{BS5400}		$N_{AU,AS,ACI}$	
		N_u	2/3	N_u	2/5	N_u	2/7
1	2	3	4	5	6	7	8
SC40-00	201	Bare section: BS5950 :A.py =190.4kN					1.06
SC40-30	314	119	2.63	107	2.94	114	2.77
SC40-60	390	145	2.69	124	3.14	135	2.88
SC40-80	424	173	2.45	142	2.98	159	2.66
SC50-00	267	Bare section using BS5950 :A.py=264.0 kN					1.01
SC50-30	403	176	2.29	155	2.59	166	2.42
SC50-60	502	219	2.30	184	2.73	203	2.48
SC50-80	618	265	2.33	215	2.87	242	2.55
IC50-4-00	123	Bare section using BS5950 : 86.0 kN					1.43
IC50-4-30	153	145	1.05	113	1.35	139	1.10
IC50-4-60	166	189	0.88	132	1.25	176	0.94
IC50-4-80	189	217	0.87	145	1.30	200	0.94
IC50-5-00	150	Bare section using BS5950: 105 kN					1.43
IC50-5-30	166	165	1.01	132	1.26	159	1.04
IC50-5-60	181	205	0.88	150	1.21	193	0.94
IC50-5-80	207	231	0.90	162	1.28	215	0.96

Table 5. Summary of tests specimens and results

Details of concrete	Specimen designation	Diameter D (mm)	Length L (mm)	Thickness T (mm)	L/D ratio	Ultimate compression load f_u (kN)	Concrete compression strength f_c (N/mm^2)	Bond stress f_b (N/mm^2)
Control concrete	CCFT1	150	300	5	2	251.6977	53.4	1.7813
	CCFT2	150	450	5	3	416.2968	54.2	1.964
	CCFT3	150	600	5	4	625.7329	53.1	2.2142
Metakaoline 5%	M^5CFT1	150	300	5	2	275.4785	58.3	1.9496
	M^5CFT2	150	450	5	3	448.5498	58.1	2.1163
	M^5CFT3	150	600	5	4	654.8125	59	2.3171
Metakaoline 10%	M^{10}CFT1	150	300	5	2	305.2645	64.4	2.1604
	M^{10}CFT2	150	450	5	3	476.1033	65.5	2.2463
	M^{10}CFT3	150	600	5	4	683.3526	65.1	2.4188
Metakaoline 15%	M^{15}CFT1	150	300	5	2	316.2435	70.1	2.2381
	M^{15}CFT2	150	450	5	3	485.2385	70.5	2.2894
	M^{15}CFT3	150	600	5	4	685.2967	71.3	2.4272
Metakaoline 20%	M^{20}CFT1	150	300	5	2	271.6493	60.3	1.9225
	M^{20}CFT2	150	450	5	3	463.789	59.8	2.1882
	M^{20}CFT3	150	600	5	4	652.2408	59.5	2.3080

Though the efficiency of the steel tube in confining the concrete core is greater when the load is applied only to the concrete section, it seems not reliable to trust just the natural bond strength to get full composite. At the ultimate load performance level, this bond stress is distributed evenly around the periphery of the interface and along a length of the steel concrete interface of the concrete filled tubular column columns.

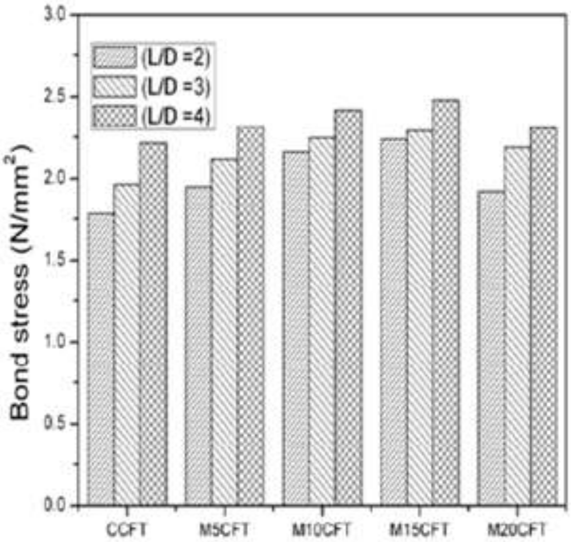

Fig 4. Bond stress of CFT and MCFT

Fig 5. Typical bond failure of CFT

Conclusion

Considerable progress has been made during the last decade in the investigation of steel–concrete composite columns, and information available is summarized in this paper. Fundamental knowledge on composite construction system such as seismic behaviour, bond strength has already been obtained by the research carried out so far. Lightweight concrete has many advantages compared to normal concrete. Its load carrying capacity is 80% of the normal concrete. Light weight aggregate concrete offer higher bond strength and compressive strength than normal concrete. The weight of the column with lightweight concrete is noted to be 20% to 26% lighter than that of the column with normal concrete of the same cross section. Hence more research has to be carried out in the properties and behaviour of lightweight concrete using different types of aggregate that depend on the availability of the material close to the region of construction.

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