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EXPERIMENTAL ASSESSMENT OF CONCENTRICALLY LOADED PRE-STRESSING CONCRETE-FILLED STEEL TUBULAR COLUMNS

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Although expansive additives are frequently used in contemporary concrete-filled steel tubular (CFST) structures to improve the bond between concrete and steel tubes, little information is available regarding their influence on the mechanical characteristics of CFST columns. This reflects the pressing need to investigate the impacts of the pre-stressing achieved through the expansive additives, especially on the concrete confinement and axial load capacity of CFST. This paper thus discusses the results of concentric load tests carried out for 12 pre-stressing CFST columns to assess their axial load capacity and modes of failure. The main parameters investigated are the concrete compressive strength (40, 50 and 90 MPa) and the dosage of the expansive agent (0%, 6%, 12% and 24% by mass of cement). The results indicate that the axial load capacity is improved by increasing both the concrete compressive strength and the expansive additive dosage. The expansive additive has an important influence on the confinement effect of CFST. The paper presents new test results that contribute to fill a gap in the literature and provides insights into the behavior of concentrically loaded pre-stressing CFST columns.

Keywords: CFST, Expansive additive, Confinement, Axial load capacity, Concrete strength, Ductility.

1 INTRODUCTION

The current trend in high-rise buildings is the use of composite concrete-steel columns in order to reduce the cross section dimensions. The use of concrete-filled steel tubes (CFST) has been introduced as an alternative for concrete-steel composite columns. The passive confinement of concrete by the steel tube increases its loading carrying capacity besides the increase of the load needed to cause local buckling of the steel tube, therefore reducing the column cross section and enabling the use of longer columns (i.e. slender columns). Recently, concrete admixtures, which counteract the shrinkage of concrete were developed. These admixtures could be used to produce expansive-concrete (EC). The use of EC in CFST will increase the confinement level exerted by the steel tubes on concrete, which will have a direct impact on the behavior of the column. Many test results related to the behavior of CFST columns are available in the literature (e.g., Sakino *et al.* 2004, De Oliveira *et al.* 2009, Dundu 2012, Perea *et al.* 2012). However, the number of expansive-concrete-filled steel tubes (ECFST) tests is limited (e.g., Lu *et al.* 2007, Xu *et al.* 2009, Wang *et al.* 2011). The objective of this study is to investigate the behavior of ECFST short columns subjected to axial compression force through a series of tests. The effect of increasing the pre-stressing level due to the use of EC on enhancing strength and behavior is studied. Test parameters include the concrete strength level and expansion agent dosage. The experimental investigation of a range of parameters increases the existing test results and provide practical recommendations regarding the behavior of ECFST columns that are increasingly used in modern high-rise buildings.

2 MATERIAL PROPERTIES

The hollow steel tubes used in the present study are cut from one single 6.0 m long cold rolled circular tube with an outer diameter (D) and a wall thickness (t) of 89.6 mm and 2.0 mm, respectively. A standard tensile test is carried out to obtain the material properties of the steel tube. One coupon is cut from the 6.0 m tube and machined according to the ASTM requirements (ASTM 2013). The sample preparation, measurement of coupon geometrical properties, and testing speed are carried out as per the ASTM requirements. The test results indicate that the yield strength and tensile strength are 239 and 303 MPa, respectively.

Table 1. Details of the three concrete mixtures with 0% expansive additive.

Material	**Mix Reference**		
	M1	**M2**	**M3**
Cement (kg/m^3)	350	450	605
Silica fume (kg/m^3	0	0	110
Water (kg/m^3)	158	180	157
Maximum aggregate size (mm)	10	10	10
Coarse aggregate (kg/m^3)	1290	1105	1105
Crushed stone sand (kg/m^3)	0	320	187
Dune sand (kg/m^3)	645	377	238
Superplasticizer (kg/m^3)	0	0	9
Average cylinder strength (MPa)	38	52	92

Since the primary objective of this study is to investigate the impacts of pre-stressing on the axial-load carrying capacity of ECFST with different concrete strength values, the column specimens are designed to produce different confinement/pre-stressing levels through the use of different concrete mixes. The concrete of the composite column specimens is mixed in a number of batches with three concrete strength values. An expansive agent in a powder form with both expanding and super-plasticizing actions is used in the present study (MAPEI 2015). To obtain different pre-stressing levels, the expansive additive (EA) is added in different dosages relative to the cement weight (i.e., 0%, 6%, 12% and 24%). The expansive additive replaced the same amount of cement. For all concrete mixtures, coarse aggregate is crushed dolomite with 10mm maximum size and the fine aggregate is a mixture of crushed stone sand and dune sand. From each concrete batch, three cylinders 100mm in diameter and 200mm in height are prepared and tested at 28 days. The adopted concrete mixes without the expansive additive are outlined in Table 1.

3 PREPARATION OF SPECIMENS

Bonded CFST specimens are tested in the present study with an axial load applied to the composite steel-concrete section. Twelve steel tubes with an outer diameter (D) of 89.6 mm are cut and machined to the required specimen length (L) of 370 mm. This specimen length is selected to reduce column slenderness and end effects. Ten concrete mixes with three different concrete strength values and four expansive agent dosages are prepared; three mixes are without the expansive agent (M1, M2 and M3), while the other seven mixes are prepared with different expansive agent ratios (M1-E6, M2-E6, M3-E6, M1-E12, M3-E12, M1-E24 and M3-E24), as shown in Table 2. The twelve CFST specimens tested in the present study are therefore divided into the four groups shown in Table 2. The specimens within each of the four groups have the same expansive agent dosage (i.e., 0%, 6%, 12% or 24%) but with different mixes, which result in different concrete strength levels. The compressive strength of the concrete core is thus the main variable within each of the investigated groups. Two identical specimen in each of the Groups B and C are cast and tested to enable verifying the test setup and accuracy of test results. It is noteworthy that the performance of expansive additive is better for high w/c ratio mixtures (i.e. M1). In particular, the concrete strength significantly increases as the expansive dosage increases from 6% to 12%. The concrete strength doesn't change much with other additive dosages. The behavior of expansive additive varies for low w/c ratio mixtures (i.e. M3), with a general trend of negative impact on concrete strength with increasing the additive dosage. This could be attributed to the fact that very little free water was available in the mixture for the expansive agent to be effectively activated.

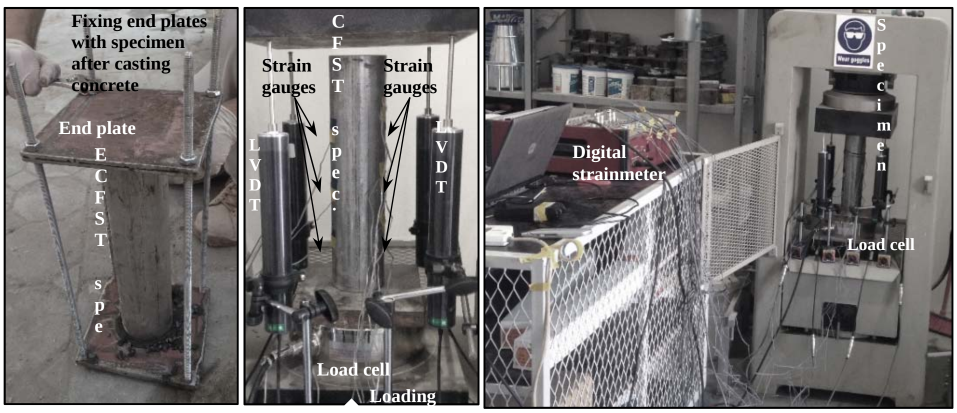
Table 2. Details of the twelve CFST specimens and the corresponding axial load capacity.

No.	Group	Specimen\ Concrete mix	Expansive Agent (EA)	$f_c^`$ (MPa)	f_y (MPa)	D (mm)	t (mm)	L (mm)	P_u (kN)
1	A	M1	0%	38	239	89.6	2	370	471
2		M2		52	239	89.6	2	370	520
3		M3		92	239	89.6	2	370	830
4	B	M1-E6	6%	38	239	89.6	2	370	564
5		M2-E6		45	239	89.6	2	370	577
6		M3-E6		77	239	89.6	2	370	928
7		M3-E6		77	239	89.6	2	370	949
8	C	M1-E12	12%	63	239	89.6	2	370	543
9		M1-E12		63	239	89.6	2	370	574
10		M3-E12		85	239	89.6	2	370	804
11	D	M1-E24	24%	59	239	89.6	2	370	565
12		M3-E24		71	239	89.6	2	370	688

In order to arrive at an effective pre-stressing action during the hardening process, two end plates with a thickness of 10 mm are fabricated and tied to each specimen; one plate at the base that is also used to support the wet concrete during casting, and another plate at the top. These two plates are tied with each specimen immediately after casting and vibrating concrete using four steel rods, as illustrated in Figure 1(a). The two end plates are then removed on the test day.

4 TEST SETUP

The specimens are tested 28 days after casting of concrete. Each CFST specimen is effectively instrumented to accurately assess its behavior. Four linear displacement transducers LVDTs (TML® CDP-100) are placed symmetrically around the specimen to measure the overall deformations, as shown in Figure 1(b). Three sets of uniaxial strain gauges (TML® FLA-05-11) are bonded on the exterior surface of each steel tube; each set includes three strain gauges that are located at 0.25, 0.5 and 0.75 of the specimen height/length. Two of the strain gauges groups are used to measure the longitudinal strains at two opposite sides of the CFST specimens, while the third group measures circumferential strains. The axial load is applied to the specimens by a 5000 kN compression testing machine. The applied load, longitudinal and circumferential strains, and longitudinal deformations are recorded on-line using a 30-channel static/dynamic digital strainmeter (TML® DRA-30A), as shown in Figure 1(c). Still cameras are used to capture images of the specimens and the development of failure modes during testing.



(a) (b) (c)

Figure 1. Fabrication and testing process: (a) fixing end plates after casting of concrete; (b) arrangement of measuring devices; and (c) overall test setup.

5 TEST PROCEDURE AND RESULTS

The behavior of CFST columns are influenced by the difference between the Poisson‘s ratio of concrete and steel. Since the Poisson’s ratio of concrete is slightly lower than that of steel, the steel tube wall will be separated from the concrete core in the initial loading stages. With increasing axial load, the concrete lateral deformation reaches that of the steel tube, which starts developing tensile hoop stresses (Sakino et al. 2004). The confining effect imposed by the steel tube on concrete results in a notable increase in specimen axial load capacity. A summary of the properties and load bearing capacities (P_u) of the 12 CFST columns tested in this study is shown in Table 2. Figure 2(a-c) depicts the load-deformation relationships of the reference CFST columns.

The initial axial load-deformation behavior is generally linear elastic up to the ultimate load. For Group A specimens, the initial stiffness is notably higher for the specimen with a higher strength concrete (HSC), as shown in Figure 2(a). Increasing the concrete strength from 40 MPa to 90 MPa significantly increases the axial strength capacity by 76% (i.e., from 471 kN to 830 kN). The axial strength capacity is observed at an axial strain ranging from 0.32% to 0.77% for the M3 and M1 specimens, respectively. The behavior of normal strength concrete (NSC) short CFST columns (i.e., for the M1 and M2) after cracking of concrete is very ductile and a high axial strain is observed before failure. For the HSC specimen, rapid strength degradation is observed and the load drops to 58% of the maximum axial strength. The CFST short columns typically fail by diagonal cracking of concrete core.

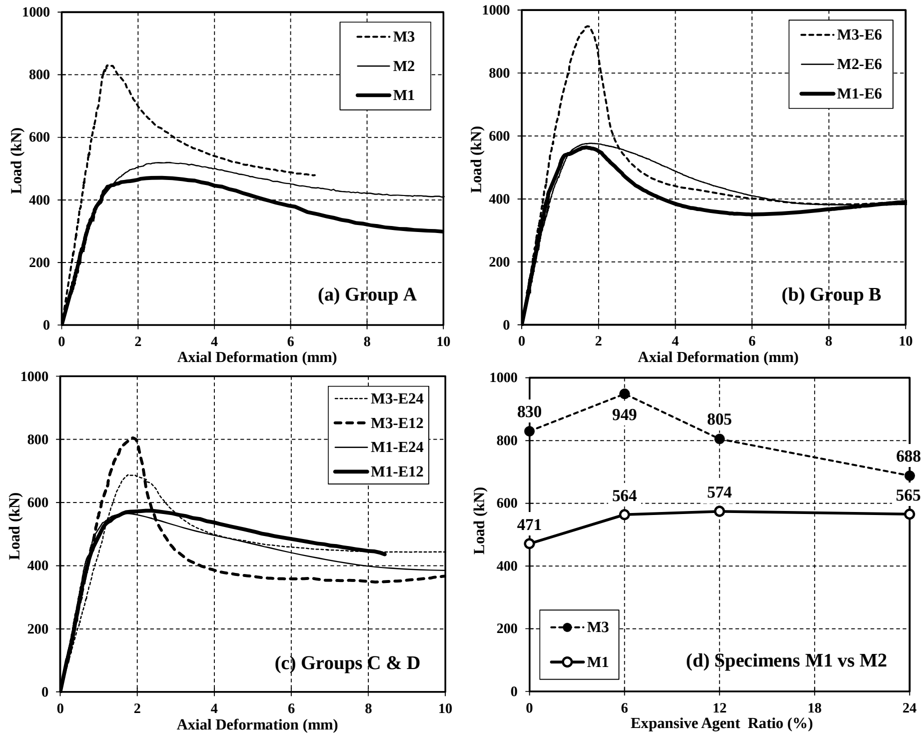


Figure 2. Effect of concrete compressive strength and expansive agent dosage on the load-deformation relationship and axial load capacity of CFST columns.

The comparison between the load-deformation relationships of Groups A and B CFST specimens illustrates the impacts of expansive additive on axial load capacity, as shown in Figure 2(a-b). The ECFST columns provided with a 6% expansive agent exhibit an increase in the axial load capacity of 14% to 20% for the M3 and M1 specimens, respectively. The axial strength capacity is observed for all specimens at an axial strain ranging from 0.45% to 0.48%. Despite the observed improvement in the axial load capacity of Group B specimens, the behavior of ECFST columns is less ductile compared with that of Group A columns. The adverse effect of expansive additive is also observed on the axial strength capacity of the ECFST columns when the expansive agent dosage is increased to 12% and 24%, particularly for the HSC specimens, as shown from Figure 2(c). The axial load capacities of M1 and M3 specimens summarized in Figure 2(d) suggest that the optimum expansive agent dosage for the ECFST short columns is 6% for different concrete strength levels.

6 CONCLUSIONS

Twelve bonded CFST specimens were divided into four groups according to their concrete strength and expansive agent dosages. Each CFST column was effectively instrumented using four LVDTs and nine uniaxial strain gauges to accurately assess its behavior. Test results indicated that increasing the concrete strength significantly increased the axial strength capacity of CFST columns by up to 76%. The ECFST short columns typically failed by diagonal cracking of concrete core. Although the ECFST columns provided with a 6% expansive agent exhibited an increase in the axial load capacity of 14% to 20%, they were less ductile than the CFST columns. The adverse effect of expansive additive was observed on the axial strength capacity of the ECFST columns when the expansive agent dosage was increased to 12% and 24%, particularly for HSC specimens. The test results suggested that the recommended expansive agent dosage for the ECFST short columns is 6% for different concrete strength levels.

Acknowledgments

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