Thin-Walled Structures 106 (2016) 390–406

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Experimental study on seawater and sea sand concrete filled GFRP and stainless steel tubular stub columns

Y.L. Li [a], X.L. Zhao [a,*], R.K. Raman Singh [b,c], S. Al-Saadi [b]

[a] Department of Civil Engineering, Monash University, Clayton, Victoria, Australia
[b] Department of Mechanical and Aerospace Engineering, Monash University, Clayton, Victoria, Australia
[c] Department of Chemical Engineering, Monash University, Clayton, Victoria, Australia

ARTICLE INFO

Article history:
Received 27 February 2016
Received in revised form
19 May 2016
Accepted 19 May 2016

Keywords:
Seawater sea sand concrete (SWSSC)
GFRP
Stainless steel
Axial compression
Local buckling

ABSTRACT

This paper presents an experimental investigation on mechanical and associated properties of seawater and sea sand concrete (SWSSC) filled glass fibre reinforced polymer (GFRP) and stainless steel (SS) circular tubes. A proper SWSSC mix was developed to achieve the target strength and desirable workability. A total of 24 stub columns, including hollow sections and SWSSC fully filled tubes or double-skin tubes, were tested under axial compression with the load applied to concrete and tubes simultaneously. The stress-strain curves of the core concrete indicate that concrete strength and ductility is enhanced due to the confinement effect. Discussion focuses on the influence of tube diameter-to-thickness ratio, outer tube types and inner tube types on concrete confinement. Capacity formulae are proposed to estimate the load carrying capacity of SWSSC fully filled SS or GFRP tubes, and that of double skin tubes with four combinations of inner and outer tubes, i.e. SS and SS, SS and GFRP, GFRP and GFRP and GFRP and SS.

1. Introduction

Concrete-filled tubes (CFTs), which are composed of core concrete and encasing tubes, have been widely used in civil engineering, such as for high-rise buildings and bridge piers. CFTs exhibit large load-carrying capacity and good seismic performance mainly due to the confinement effect on core concrete provided by the encasing tube. Past researches (as summarised in [1]) have indicated that the circular tubes can provide substantial strength enhancement and ductility in comparison to the square or rectangular tubes. The confinement effect of circular CFT is considered in most of the current design codes. Based on the cross-section configuration, concrete-filled tubes can be divided into fully concrete filled tubes and concrete-filled double-skin tubes.

The increase in global population [2] has led to an increasing demand for resources (e.g. fresh water) and infrastructure (e.g. buildings, bridges). The huge demand of concrete, which is the most commonly used material for building infrastructure, is exacerbating the resource shortages (e.g. fresh water, river sand) and causing serious environmental impact (e.g. emission of CO_2 during the production of Portland cement). One solution to these problems is to utilize seawater, sea sand, and geo-polymers (e.g. slag, fly ash) to replace fresh water, river sand and ordinary Portland cement (OPC) respectively. Another benefit of using geo-polymers is that the expansion caused by alkali silica reaction (ASR), which potentially causes concrete cracking, is considerably less in geo-polymer-based concrete than in OPC-based concrete [3]. The mechanical properties of alkali-activated seawater and sea sand concrete (SWSSC) are generally similar to those of conventional Portland concrete [4]. However, conventional carbon steel tubes are not suitable to provide confinement to SWSSC because of the highly corrosive condition caused by chloride ions of seawater in SWSSC itself [5]. Therefore, the stainless steel (SS) and fibre reinforced polymer (FRP) are adopted in this research due to their greater corrosion resistance.

Extensive studies have been conducted on concrete-filled carbon steel tubes (for fully filled tubes: e.g. [1,6–9]; for double-skin tubes: e.g. [10–13]). In recent years, there is an increasing interest in replacing carbon steel by stainless steel (SS) in marine environment due to its greater corrosion resistance. Several experimental investigations (e.g. [14–16]) have been conducted on fully concrete filled SS tubular columns, which indicate that the performance is quite good and current design codes are conservative for concrete-filled SS tubes. However, very little studies have been conducted on concrete-filled double-skin SS tubes [17].

As a promising material, fibre reinforced polymer (FRP) is now increasingly used in concrete-filled tubes. Several studies (e.g. [18,19]) have been carried out on concrete-filled FRP wraps (with fibres exclusively oriented in hoop stress direction) and some stress-strain models have been proposed for the FRP wrap

* Corresponding author.
E-mail address: ZXL@monash.edu (X.L. Zhao).

http://dx.doi.org/10.1016/j.tws.2016.05.014
0263-8231/

Nomenclature

A_c	cross-section area of concrete
A_{cn}	nominal concrete area
A_i	cross-section area of inner tube
A_o	cross-section area of outer tube
A_s	cross-section area of steel tube
D_i	diameter of inner tube
D_o	diameter of outer tube
E_h	elastic modulus of GFRP in hoop direction
E_l	elastic modulus of GFRP in longitudinal direction
E_o	initial elastic modulus of stainless steel
$f_{av,i}$	average stress for the inner tube
$f_{0.2}$	0.2% proof stress
f_c'	concrete strength
f_{cc}'	confined concrete strength
f_{ck}	characteristic strength of concrete
f_l	confining stress
f_{scy}	nominal yielding strength of composite sections
f_{un}	nominal ultimate strength
f_y	yield strength (= $f_{0.2}$ for SS)
f_{yi}	yield strength of inner tube
f_{yo}	yield strength of outer tube
L	specimen length
N_p	predicted capacity
N_t	test capacity
t_i	thickness of inner tube
t_o	thickness of outer tube
Δ	axial end shortening
ε_{co}	ultimate strain of concrete
ε_{cu}	ultimate strain of confined concrete
ε_{uh}	ultimate strain of GFRP in hoop direction
ε_{ul}	ultimate strain of GFRP in longitudinal direction
χ	void ratio
ν	Poisson's ratio
ξ	confinement factor
σ_{res}	residual stress of GFRP tube
σ_u	ultimate strength of GFRP tube

confined concrete [18,20]. In recent years, some researchers (e.g. [21,22]) also looked into fully concrete filled FRP tubes (with fibres oriented both in hoop and longitudinal directions) for the use of tubes as formwork. To the best of authors' knowledge, only one experimental study [21] has been conducted on concrete-filled double-skin tubes (using specimens with FRP as both outer and inner tubes) but no study on concrete-filled double-skin tubes (FRP as outer and SS as inner tube) is reported.

This paper reports an overall experimental investigation on seawater and sea sand concrete (SWSSC) filled circular tubular columns, including SWSSC fully filled tubes and double-skin tubes with different combinations of tube materials (stainless steel (SS) or glass fibre reinforced polymer (GFRP)). Firstly, a proper SWSSC mix was developed to achieve the target strength and desirable workability. The material properties of stainless steel and GFRP were determined by standard tensile tests. Axial compressive test was conducted on a total of 24 stub columns, including SWSSC-filled SS tubes, SWSS-filled GFRP tubes and corresponding hollow section tubes. An understanding of comparative properties has been developed based on the existing theories and the test results of this study. Finally, new methods are proposed to estimate the strength of SWSSC-filled SS tubes and GFRP tubes. It is worthwhile to mention that this paper forms part of a large research program on hybrid SWSSC construction being carried out at Monash University in collaboration with The Hong Kong Polytechnic University and Southeast University, China. In the next stage, the SWSSC-filled tubes will be immersed in seawater for different durations to assess the influence of corrosive environment.

2. Experimental investigation

2.1. Specimens

A total of 24 circular stub columns, including 8 hollow tubes, 8 SWSSC fully filled tubes, and 8 SWSSC-filled double-skin tubes, were prepared and tested in the present study. The specimens were made of seawater sea sand concrete (SWSSC), or stainless steel (SS) tube, and /or GFRP tubes. Four sizes of tubes (with nominal diameter of 50 mm, 101 mm, 114 mm, and 165 mm and with nominal thickness of 3 mm) were used for the specimens and the length of all the specimens was around 400 mm long which avoided the global buckling and the influence of end effect.

The dimensions of the test specimens are presented in Table 1, where the failure loads (N_t) are also given. The label of specimen consists of outer tube material ("S" for stainless steel and "F" for GFRP), outer tube nominal diameter ("50", "101", "114", and "165"), inner tube material (only for double-skin tubes), inner tube nominal diameter (only for double-skin tubes), and cross-section type indicator ("H" for hollow section and "C" for concrete-filled section). For example, S114-C refers to fully SWSSC-filled stainless steel tube with D_o of 114 mm, and S114-F50-C refers to SWSSC-filled double-skin tube with an outer stainless steel tube (D_o of 114 mm) and an inner GFRP tube (D_i of 50 mm) (Fig. 1).

2.2. Material properties

2.2.1. Seawater and sea sand concrete (SWSSC)

Alkali activated slag concrete with seawater and sea sand was

Table 1
Details of specimens.

	Outer tube (mm)			Inner tube (mm)			N_t (kN)
	D_o	t_o	Mat.	D_i	t_i	Mat.	
S50-H	47.9	2.79	SS	N/A	N/A	N/A	118
S101-H	101.2	2.81	SS				335
S114-H	114.0	2.86	SS				355
S165-H	168.3	3.23	SS				545
F50-H	51.2	3.20	GFRP				98
F101-H	100.2	2.94	GFRP				199
F114-H	115.3	3.03	GFRP				206
F165-H	158.0	2.96	GFRP				213
S50-C	47.9	2.77	SS				199
S101-C	101.2	2.83	SS				729
S114-C	113.9	2.88	SS				800
S165-C	168.2	3.15	SS				1522
F50-C	51.1	3.07	GFRP				244
F101-C	100.1	3.13	GFRP				670
F114-C	115.2	3.13	GFRP				813
F165-C	158.2	3.14	GFRP				1336
S114-S50-C	114.5	2.87	SS	47.9	2.73	SS	909
S165-S101-C	167.8	3.18	SS	101.2	2.80	SS	1409
S114-F50-C	114.2	2.95	SS	51.2	3.20	GFRP	799
S165-F101-C	168.4	3.22	SS	100.3	3.06	GFRP	1167
F114-S50-C	114.8	2.91	GFRP	47.9	2.82	SS	795
F165-S101-C	158.0	2.92	GFRP	101.8	2.91	SS	880
F114-F50-C	114.7	2.93	GFRP	51.3	3.09	GFRP	872
F165-F50-C	158.3	3.13	GFRP	100.3	3.13	GFRP	1301