Thin-Walled Structures 124 (2018) 291–302

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Dune sand concrete-filled steel tubular (CFST) stub columns under axial compression: Experiments

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ARTICLE INFO

Keywords:
Concrete-filled steel tubes (CFST)
Dune sand concrete
Stub columns
Axial compression
Ultimate strength

ABSTRACT

The behaviour of dune sand concrete-filled steel tubular (CFST) stub columns under axial compression was experimentally investigated in this paper, where the nominal cube strength of concrete was 60 MPa. A total of 24 specimens including 20 dune sand CFST stub columns and 4 reference hollow steel tubular stub columns were tested. The effects of tube thickness, cross-sectional dimension and concrete infill on the behaviour of the composite stub columns were investigated. The results showed that, similar to conventional CFST stub columns, the tested dune sand CFST stub columns behaved in a ductile manner and displayed an outward buckling failure model with high compressive strength. It indicates that it is feasible to use dune sand to replace normal sand to fabricate CFST columns in regions close to deserts. Comparisons were made between the test results and the predicted ultimate strength using the existing codes AIJ (2008), AISC360-10 (2010), BS5400 (2005), DBJ/T13-51-2010 (2010) and EC4 (2004). Generally, these codes are conservative but acceptable for predicting the ultimate strength of dune sand CFST stub columns.

1. Introduction

Concrete-filled steel tubular (CFST) columns have been increasingly used in buildings, bridges, and transmission towers owing to their structural superiorities and constructional conveniences. In the past several decades, extensive studies have been carried out on CFST stub columns, such as Schneider [1], Roeder et al. [2], Uy [3], Han [4], Lam and Williams [5], Tao et al. [6], Ellobody et al. [7], Liang et al. [8], Liew and Xiong [9], Zhao and Parker [10], Han et al. [11], Ren et al. [12] and Lai and Ho [13]. Some of these research outcomes have been summarised by Han et al. [14]. In recent years, a few new types of CFST stub columns filled with various kinds of concrete have been studied, such as lightweight aggregate concrete [15–17], polymer cement concrete [18,19], fibre reinforced concrete [20,21], recycled aggregate concrete [22,23], rubberised concrete [24], steel slag concrete [17] and waste glass concrete [17].

As the demand for fine aggregate is escalating rapidly in construction industry, river sand resources are excessively exploited all over the world. As a result, new sources of sand should be considered, such as dune sand. Take China for instance, the dune area accounts for nearly a quarter of the Chinese land area; the abundant dune sand may be used in concrete mixture instead of the river sand. Compared with river sand, dune sand however possesses some critical defects including low fineness modulus and poor gradation [25–27]. Possible detrimental effects such as alkali silica reaction induced by using dune sand might also take place [28], which requires further investigation in the future.

In the last ten years, dune sand has been tentatively used in mortar [25] and concrete [25–27] as fine aggregate replacement. Zhang et al. [25] experimentally investigated the mechanical properties of concrete made of two types of dune sand as fine aggregate. The results indicated that dune sand could be used as fine aggregate in concrete for general engineering construction, if used properly. Al-Harthy et al. [26] experimentally studied the effect of dune sand on the workability, strength and elastic modulus of concrete with different replacement ratios from 10% to 100%. The results showed that when the dune sand content reached a high level (above 50%), the workability and slump decreased with the increase of dune sand content. Generally, the strength also decreased with the increase in dune sand replacement. However, the maximum strength loss was less than 25% when fine aggregate was fully replaced by dune sand. Luo et al. [27] presented the study on the properties of concrete made with dune sand from Australian desert with a constant water-cement ratio of 0.5. The results revealed that, at a high level of sand-cement ratio (> 1.41), the excessively fine particles led to reduction in the workability and strength

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https://doi.org/10.1016/j.tws.2017.12.006
Received 22 September 2016; Received in revised form 24 November 2017; Accepted 4 December 2017

Nomenclature

A_c	cross-sectional area of dune sand concrete
A_s	cross-sectional area of the steel tube
A_{sc}	cross-sectional area of the dune sand CFST stub column ($= A_c + A_s$)
B	cross-sectional width of the square section
D	cross-sectional diameter of the circular section
DI	ductility index
E_c	elastic modulus of concrete
E_s	elastic modulus of steel
E_{sc}	elastic modulus of CFST
f_{ck}	characteristic strength of concrete ($= 0.67f_{cu}$ for normal strength concrete)
f_{cu}	cube strength of concrete
f_c'	cylinder compressive strength of concrete
f_y	yield stress of steel
f_u	ultimate strength of steel
H	height of the stub column
N	axial load
N_{uc}	predicted ultimate strength
N_{ue}	measured ultimate strength
RI	rigidity index
SI	strength index
t	tube thickness
μ_s	Poisson's ratio of steel
Δ	axial shortening
Δ_{ue}	axial shortening corresponding to the ultimate strength
$\Delta_{85\%}$	axial shortening when the axial load falls to 85% of the ultimate strength
α	steel ratio ($= A_s/A_c$)
ε	axial strain
ε_y	yield strain of steel
ε_u	ultimate strain
ε_{uc}	predicted ultimate strain
ε_{ue}	measured ultimate strain
$\bar{\sigma}_u$	ultimate stress

of dune sand concrete. The above investigations highlight that fresh concrete mixture with excessive dune sand normally has high cohesiveness, small slump, poor fluidity and low workability. In addition, the compressive strength and elastic modulus of the dune sand concrete usually decrease as well. However, when dune sand is used in CFST members, the negative influence of dune sand on the structural performance is probably not as critical as that on the performance of pure concrete, since the interaction between the steel tube and concrete might mitigate the disadvantages of using dune sand. Wang et al. [29] experimentally investigated the behaviour of CFST stub columns and beams using dune sand to replace 10% of fine aggregate in concrete. The research results showed that the in-filled dune sand concrete with small replacement ratio could work well with the outer steel tube in CFST stub columns and beams. It was found that the failure modes and behaviour of dune sand CFST specimens were similar to those of conventional CFST members.

The above literature review indicates that the research on dune sand CFST columns is still limited, and it seems that no study has been conducted on CFST columns using only dune sand as fine aggregate. It is of importance to evaluate the performance of such dune sand CFST columns using only dune sand as fine aggregate (dune sand CFST columns for short) and to compare with those CFST members using dune sand as a 10% replacement of fine aggregate as well as conventional CFST members. Moreover, the feasibility to use dune sand CFST columns in regions close to deserts need to be further evaluated. This paper thus presents an experimental investigation on the ultimate strength and failure patterns of dune sand CFST stub columns. The main objectives of this research are threefold. First, to report a series of tests on dune sand CFST stub columns under axial compression and to study the influence of main factors on their ultimate strength. Second, to compare the axial compressive behaviour of dune sand CFST stub columns with that of CFST stub columns using dune sand as 10% of fine aggregate and conventional CFST stub columns, and third, to recommend design equations that are able to predict the ultimate strength of dune sand CFST stub columns under axial compression.

2. Experimental investigation

2.1. Specimen preparation

A total of 24 stub columns were tested, including 12 square sections and 12 circular sections; both series had 10 dune sand CFST specimens and 2 reference specimens with hollow sections. Fig. 1 exhibits the schematic views of the square and circular dune sand CFST stub columns. To obtain reliable test results, two duplicated specimens were prepared in each case. The main parameters varied in the tests include: (1) cross-sectional shape: square and circular sections; (2) tube thickness (t): 1.98, 2.90 and 3.82 mm; (3) cross-sectional width (B) or diameter (D): 100, 150 and 200 mm; (4) cross-section type: with or without concrete infill.

Details of the specimens are presented in Table 1, where H is the height of the stub column, α is the steel ratio defined as $\alpha = A_s/A_c$. A_s and A_c are the cross-sectional areas of the steel tube and concrete, respectively. The specimens are identified using the following designation system: the initial letter "s" or "c" stands for the square or circular section, respectively; the second letter "h" (if any) stands for the hollow section without concrete infill; the first number stands for a group of steel tubes with the same width and thickness; and the last number 1 or 2 is used to differentiate the two duplicate specimens in the same group. For example, the specimen with the label "sh1-2" denotes the second specimen in the first group of the square stub columns, where the steel tube is not filled with concrete.

All the steel tubes were fabricated using mild steel sheets. To make a square steel tube, two steel plates were cut and cold rolled into channels, which were then tack welded into a square section with longitudinal V butt welds. In contrast, a circular steel tube involved cold-forming a steel plate into a circular shape and welding the longitudinal seam. A 20 mm thick steel endplate was welded to one end of each steel tube. Three types of steel with thicknesses (t) of 1.98, 2.90 and 3.82 mm

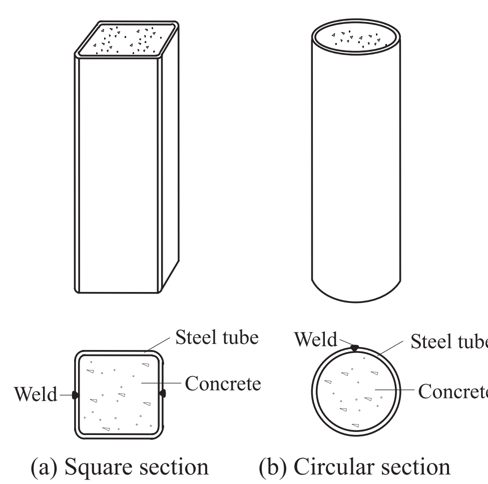

Fig. 1. Schematic views of dune sand CFST stub columns.