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Column tests of dodecagonal section double skin concrete-filled steel tubes

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ABSTRACT

A series of tests on dodecagonal section double skin concrete-filled steel columns (DCS) were carried out in this study. Column specimens having different lengths ranged from 1000 mm to 3500 mm were tested. The behavior and strengths of dodecagonal section double skin concrete-filled steel columns were investigated. In addition, local bucking of inner and outer steel tubes were also investigated. Material properties of the concrete and steel used in the test specimens were measured. The test strengths are compared with the design strengths calculated using the proposed methods based on current AISC Specification and Eurocode for the design of composite structural members. The suitability of design method proposed by other researcher for circular section double skin concrete-filled steel columns for dodecagonal section specimens was also evaluated.

1. Introduction

Double skin concrete-filled steel (DCS) tubular columns consist of two concentric thin steel tubes with concrete sandwiched between them. As a new form of concrete-filled steel tube (CFT), DCS holds almost all the advantages of the traditional ones, such as high capacity, good ductility and easy construction. In addition, DCS performs better under cyclic loading, thus can be used in seismic resistant structures. Moreover, DCS has lighter weight, higher bending stiffness, and higher fire resistance capacity [1,2].

Reviewing the past studies on DCS, we can easily notice that many experimental and analytical studies that have been performed focused on the behavior of circular hollow sections or square hollow sections [3–13]. In this study, a new dodecagonal section specimen was proposed. It is expected to have better local buckling resistance compared with square section specimens and also to have the advantage of easy fabrication and flat surface for connection compared with circular section specimens.

This paper is devoted to investigate axially loading characteristics of DCS stub columns and long columns where both inner and outer tubes are dodecagonal hollow sections, as shown in Fig. 1(a). Special attention was placed herein on the measured strength and strain in order to discuss the behavior of DCS. Finally, the tested strengths are compared with predicted strengths calculated using several different design methods.

2. Experimental investigation

2.1. Test specimens

The test specimens were fabricated by molding a flat steel plate into a dodecagonal or round (for circular section specimens) shape, and then the ends of the steel tubes were cut to specified lengths of 1000 mm, 2000 mm, 2500 mm and 3500 mm. The outside surface of inner steel tube and insides surface of the outer steel tubes were wire brushed to remove any rust and loose debris present. Both outer and inner steel tubes were placed centric. The self-compacting concrete was cured without any vibration. During curing, a very small amount of longitudinal shrinkage occurred at the top of the column. High strength cement was used to fill this longitudinal gap before the welding of the top steel end plate. Two 20 mm thick steel plates were welded to both ends of the specimens to ensure full contact between specimen and end bearing.

The measured cross-section dimensions and specimen length for each test specimen are shown in Tables 1 and 2. Fig. 1(a) and (b) shows the cross section of dodecagonal section and circular section specimens, respectively. The 1000 mm columns (columns having the length of 1000 mm) were designed to study the local buckling of the specimens.

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Nomenclature

A_c cross-sectional area of concrete;
A_{ce} nominal cross section area of concrete, given by $\pi(D_o-2t_{so})^2/4$;
A_{si} cross-sectional area of inner tube;
A_{so} cross-sectional area of outer tube;
A_{sco} cross-sectional areas of outer tube and sandwiched concrete ($=A_{so}+A_c$);
A_{eff} effective cross sectional area;
C_1 (Han's Method) $\alpha/(1+\alpha)$;
C_1(AISC Standard) coefficient for calculation of effective rigidity of a composite compression member;
C_2 $(1+\alpha_n)/(1+\alpha)$;
D_i outside diameter of inner tube;
D_o outside diameter of outer tube;
E_c elastic modulus of concrete;
E_{cm} secant modulus of elasticity of concrete;
E_s elastic modulus of steel;
EI_{eff} effective stiffness of composite section;
f_c' specified compressive strength of concrete;
f_{ck} (Han's Method) characteristic strength of concrete;
f_{ck} (Eurocode) characteristic compressive cylinder strength of concrete at 28 days;
f_{cd} cylinder compressive strength of concrete;
f_{yi} yield strength of inner tube;
f_{yo} yield strength of outer tube;
f_{scy} composite strength of outer tube and sandwiched concrete;
F_{cr} critical stress;
F_e elastic buckling stress of inner tube;
I_c moment of inertia of concrete cross section about the elastic neutral axis of the composite section;
I_{si} moment of inertia of inner tube cross section about the elastic neutral axis;
I_{so} moment of inertia of outer tube cross section about the elastic neutral axis of the composite section;
K effective length factor;
L laterally unbraced length of member;
N_{cr} elastic critical force for the relevant buckling mode based on the gross cross sectional properties;
$N_{i,u}$ compressive capacity of the inner tube;
$N_{osc,u}$ capacity of the outer tube with the sandwiched concrete;
$N_{uc,h}$ predicted ultimate strength using Han's method;
$N_{uc,A}$ predicted ultimate strength using the AISC Standard;
$N_{uc,E}$ predicted ultimate strength using the Eurocode;
P_e elastic critical buckling load;
P_{n1} compressive capacity of inner tube;
P_{n2} compressive capacity of outer tube with the sandwiched concrete;
P_{no} $F_{cr}A_{so}+0.7f_c' A_c$;
r radius of gyration of inner tube;
Q_s net reduction factor of cross sections composed of only unstiffened slender elements in uniform compression;
t_i thickness of inner tube;
t_o thickness of outer tube;
α (Han's Method) steel ratio ($=A_{so}/A_c$);
α (Eurocode) imperfection factor ($=0.49$);
α_{cc} coefficient taking account of long term effects on the compressive strength ($=1.0$);
α_n nominal steel ratio ($=A_{so}/A_{ce}$);
γ_c partial safety factor for concrete ($=1.5$);
γ_{M1} partial factor for resistance of members to instability assessed by member checks ($=1.0$);
k_σ 4;
ε $\sqrt{235/f_y}$;
η_{ao} $0.25(3+2\bar{\lambda})\le 1.0$;
η_{co} $4.9-18.5\bar{\lambda}+17\bar{\lambda}^2\ge 0$;
θ ;
λ_o elastic-plastic critical slenderness ratio;
λ_p elastic critical slenderness ratio;
$\bar{\lambda}$ $\sqrt{N_{pl,Rk}/N_{cr}}$;
ξ confinement factor ($=\alpha_n f_{yo}/f_{ck}=A_{so}f_{yo}/A_{ce}f_{ck}$);
ρ reduction factor for plate buckling;
φ stability coefficient of axially loaded members;
χ (Han's Method)hollow section ratio, given by $D_i/(D_o-2t_o)$;
χ (Eurocode)reduction factor for the relevant buckling mode;
φ $0.5\left[1+\alpha(\bar{\lambda}-0.2)+\bar{\lambda}^2\right]$;
ψ 1.0;
MI-AVE-FLA average strain of flat portion at mid-length of inner tube;
MI-AVE-COR average strain of corner portion at mid-length of inner tube;
MO-AVE-FLA average strain of flat portion at mid-length of outer tube;
MO-AVE-COR average strain of corner portion at mid-length of outer tube;

For stub columns, the test specimens are labeled such that the type of the specimen, outer diameter of outer steel tube, nominal thickness of outer steel tube and outer diameter of inner steel tube can be identified from the label. For example, the labels "DCS500-4-300A" define the specimens as follow:

- The three letters indicate that the type of the specimen, where the prefix letter "DCS" refers to dodecagonal section double skin concrete-filled steel tubes.
- The following three digits "500" indicate the outer diameter of the outer steel tubes in mm.
- The following digit "4" is the nominal thickness of the outer steel tube in mm.
- The following three digits "300" are the outer diameter of the inner steel tube in mm.
- The last character "A" refers to repeated test specimen.

For slender columns, the test specimens are labeled such that the type of the specimen, diameter of outer steel tube, nominal thickness of outer steel tube and nominal length of the specimens can be identified from the label. For example, the labels "DCS400-4-2000A" define the specimens as follow:

- The three letters indicate that the type of the specimen, where the prefix letter "DCS" refers to dodecagonal section double skin concrete-filled steel tubes. ("CDCS" refers to circular section double skin concrete-filled steel tubes.)
- The following three digits "400" indicate the diameter of the outer steel tubes in mm.
- The following digit "4" is the nominal thickness of the outer steel tube in mm.
- The following four digits "2000" are the diameter of the inner steel tube in mm.
- The last character "A" refers to repeated test specimen.