Journal of Constructional Steel Research 117 (2016) 175–184

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental performance of concrete filled welded steel tube columns

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ARTICLE INFO

Article history:
Received 18 May 2015
Received in revised form 16 October 2015
Accepted 17 October 2015
Available online xxxx

Keywords:
Concrete filled steel tube columns
Lateral weld
Seam weld
Experiments

ABSTRACT

Effectiveness of concrete filled steel tube columns in improving life quality and safety is particularly noteworthy. Assembling columns at story levels by bolted connections is the current practice in the field. Closed section tubes do not allow bolted joint designs at intermediate locations of column length. As a result of such limitation, proper fractions of steel tubes are generally used to minimize steel waste. However, considering vast variety applications of columns, it is not always possible to use proper fractions of the tubes. In order to eliminate steel material waste, lateral welding can be employed to develop intermediate joints. However, there exists limited guidance on lateral weld design for concrete filled steel tube columns. A limited number of studies on seam welded tubes are present in the literature, but the individual paper's conclusions do not reference seam weld behavior under severe compressive loading. This paper presents results of 18 tests which were undertaken to assess the performance of laterally and longitudinally welded columns. Different L/D ratios (short, medium and long columns), D/t ratios and different lateral weld locations were studied. It has been shown that seam weld failures have slight effects on capacity and failure mode. However, seam weld failures certainly reduce ductility. On the other hand, lateral welds are very successful in transmitting compression and bending effects. It can be deduced that lateral weld joints have the potential to lead reliable and economical designs for concrete filled steel tube columns.

1. Introduction

Concrete filled steel tube (CFST) columns have promising properties compared to reinforced concrete and bare steel counterparts. Since CFST combines beneficial characteristics of steel and concrete, economical and high performance designs can be achieved. CFST columns offer high strength, high ductility, high stiffness and high energy absorption capacity [1–6]. A further achievement of CFST members is the enhanced fire resistance of structures [7–9]. Moreover, steel tube serves as permanent formwork for concrete [1,5,10–13], thus reduces construction time and cost. Local buckling of the steel tube is also delayed due to core concrete support [4,7,14–16] and confinement effect of steel tube leads to significant increase in concrete compressive strength [3].

Above advantages led CFST compression members to find use in a vast variety of engineering structures. Tall buildings [11,16,17], bridges [11,17], foundation piles [9,18], towers [4] and deep underground tunnels [19] are some examples in which CFST members have the potential to serve under high compressive actions. Since the confinement effect of circular tubes is superior [6,7,10,20], they are generally preferred in these structures which require high performance. Square and rectangular tubes offer little confinement because the walls in these tubes must resist the concrete pressure by plate bending, instead of generated hoop stress in circular sections [21].

Steel tubes are manufactured in standard lengths. In CFST applications, depending on story height of buildings and member length in other type of structures, steel tube profiles are divided into pieces and assembled again at story levels or member ends. For the proper fractions of standard tube length, there would not be any steel material waste. Considering the vast variety of applications and different needs for structures, steel material waste is quite possible due to member lengths. Unlike I, H and U profiles, tubular members have closed sections. Consequently, it is quite impossible to design bolted connections at intermediate levels of CFST columns. In these cases the only way of possible design is to utilize lateral welding which could allow intermediate joints for closed sections.

Two different types of steel tube are present in the market; (1) drawn tubes which are rolled members and also called as seamless tubes and (2) seam welded tubes. As is well known, both types of manufacturing methods are undertaken by automated machines. In drawn tubes, cross sectional properties do not differ at any point on the cross section. In seam welded tubes a longitudinal weld is utilized along the member length to join two sides of the material.

Welding introduces significant level of heat in the vicinity of weld and causes local material degradation. Cooling of the weld metal leads tensile residual stresses in the weld bead on the order of the yield strength of the annealed material and compressive stresses elsewhere [22]. Research on longitudinally welded built-up H and box section steel columns shows that residual stresses have influence on member compression behavior [14,22]. Moreover, welded columns tend to

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http://dx.doi.org/10.1016/j.jcsr.2015.10.013
0143-974X/

have a greater out-of-straightness [23] which may compromise compression performance of members. Although welding leads some concerns about performance of structures, by careful handling techniques it can allow faster, more practical and economical designs.

For many years, significant amount of research has been directed towards the investigation of compression performance of CFST columns [3,6,7,10,13,15–17,20]. However, there exist a few studies related to longitudinal weld in CFST columns. Experimental programs conducted on concrete filled box sections [2,14], seam welded circular sections [3] and built-up cold formed steel rectangular sections [12] show that welding has the potential to be used in CFST construction. However the individual paper conclusions relating to longitudinal welded CFST columns do not reference the weld behavior and reliability under compressive loading. In addition to this, the compression behavior of laterally welded steel tubes has not been studied. In this paper, results of a new in depth experimental study are presented to provide an insight into compression performance of concrete filled laterally welded steel tubes. Towards this aim, 18 specimens were tested to failure under concentric compressive loading. The studied parameters are length to diameter (L/D) ratio of tubes, diameter to thickness (D/t) ratio of tubes and lateral weld location. Since the column specimens were manufactured using seam welded tubes, examination of longitudinal seam weld behavior under compression is a further goal of this paper. Thus CFST columns assembled with welds and designed to function under severe compression actions may be particularly sensitive to weld behavior and thus particularly appropriate for investigation.

2. Experimental procedure

2.1. Manufacturing process of steel tubes

Steel tubes employed in present paper were manufactured in accordance with EN 10219-Cold formed welded structural hollow sections of non-alloy and fine grain steels [24]. According to this European norm steel tubes are delivered without subsequent heat treatment. The steel tubes were supplied from manufacturer and filled with concrete. The manufacturing process of cold-formed steel hollow sections is explained by Zhao et al. [25] in five steps. The first step is uncoiling of steel sheet. In the second step sheet is formed into a circular shape through sets of forming rolls. Third step includes welding of the edges of the circular shape by High Frequency Electric Resistance Welding (HF-ERW) to form circular hollow section. In the fourth step a series of rolls are employed to accurately size the circular section or turn circular section into a square or rectangular hollow section. Finally, in the fifth step tube is cut to specified standard length and prepared for dispatching. Fig. 1 provides a general scheme of circular steel tube manufacturing by cold forming.

2.2. Material properties

S235 tube steel was used for CFST column specimen preparation. Yield and tensile strengths of S235 steel are 235 MPa and 360 MPa respectively. This type of steel is weldable, so it is adaptable to weld joint applications. 100 mm × 200 mm cylinder concrete compression specimens were cast from the concrete batch. Considering the diameter of steel tubes, coarse aggregate of maximum diameter of 10 mm and fine aggregate (sand) were used in concrete mix. Cylinders were filled in three layers and compacted carefully. After curing stage, the specimens were crushed in accordance with ASTM C39/C39M [26] to measure compressive strength. Measured average compressive strength of concrete is 75.3 MPa. In this study, this high strength concrete was intentionally preferred for composite columns. The idea behind this choice is to develop high level of stresses at weld joint to examine the integrity of the joint under severe compressive actions.

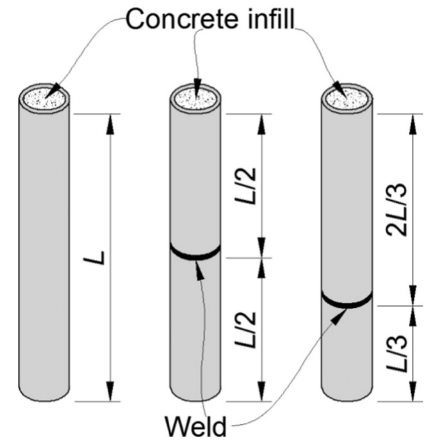

Fig. 2. Three different column configurations.

2.3. Column specimens

CFST column specimens were produced using 101 mm diameter steel tubes. Three L/D ratios and two D/t ratios were specified for column specimens. The motivation behind selecting various L/D ratios is the expectation of different failure modes for different slenderness ratios. The failure of short columns is by compressive yielding of steel and crushing of concrete and for longer columns overall instability failure mode by partial compressive yielding of steel and crushing and cracking of concrete [15]. Besides, in order to examine the lateral weld performance for different tube thicknesses, two different D/t ratios were selected.

Also, for each specimen, three different configurations were considered to examine the lateral weld behavior. First configuration of each group includes un-welded (seam welded but no laterally welded) specimen. Second configuration is the laterally welded specimen with weld location at mid-length (L/2) of the column. Finally, the third configuration consists lateral weld which is located at one third of the length (L/3) of the column. Two different locations for weld were selected to investigate the effect of location on the compression capacity of CFST columns. Schematic representation of three different configurations is depicted in Fig. 2. Table 1 presents geometrical properties of all column

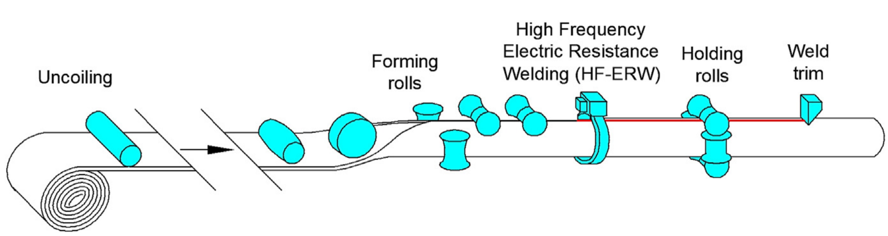

Fig. 1. Manufacturing of circular steel tubes by cold forming.