Engineering Structures 166 (2018) 16–30

Contents lists available at ScienceDirect

Engineering Structures

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

Behaviors of partially concrete-filled welded integral T-joints in steel truss bridges

Bin Cheng[a,*], Sheng Xiang[b], Wei Zuo[b], Nianguan Teng[b]

[a] State Key Laboratory of Ocean Engineering, Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

ARTICLE INFO

Keywords:
Steel truss bridge
Welded integral joint
Partial concrete filling
Elastic rigidity
Load bearing capacity

ABSTRACT

This research focuses on the structural behaviors of partially concrete-filled welded integral T-joints in steel truss bridges. The T-shape integral joints, which are composed of welded box-section members, were simply supported at chord ends so that the loading cases of horizontal force and vertical force at brace end can be considered. Static tests are first conducted for six specimens, of which three are with arc transitions at chord-to-brace corners and the other three are without arc transitions. Three cases of concrete filling in chord, i.e., hollow chord, partial concrete filling in chord, and full concrete filling in chord, were considered. The elastic and elasto-plastic behaviors including rigidities, steel strains at critical locations, failure modes, characteristic loads, and characteristic deflections of the joints were obtained. The effects of internal concrete were comparatively analyzed. Finite element models were also developed to predict the load bearing capacities of joints by considering various concrete filling ranges in the chord. The numerical outputs were validated by the test results. The influences of concrete filling length on structural behaviors including elastic rigidity, yield load, and ultimate load were revealed on the basis of numerous parametric studies. Both experimental and numerical results indicate that the joints whose chords have been partially filled with concrete are expected to provide the structural behaviors as good as those of fully concreted-filled joints, both of which are obviously higher than those of hollow joints (i.e., without concrete filling in chord). The optimal concrete filling lengths in the chord of welded integral joints are suggested to be three times the chord's sectional height by considering both beneficial and adverse effects of internal concrete.

1. Introduction

Welded integral joints have been widely used in long-span or heavy-loaded steel truss bridges where large-scale welded box-section members are employed. In these structures, the gusset plates as used to connect the separated members in traditional truss bridges (i.e., assembled joints) are discarded, and instead the same side web plates of adjacent members are integrated into a whole gusset plate at the joint location (i.e., integral joints) [1,2]. Different from the traditional assembled joints where numerous on-site welding was involved, most of the complicated welding jobs of integral joints are accomplished in factory and therefore the welding qualities are expected to be better. The integral joint segments and the member segments, both fabricated in factory, are easy to be assembled into the whole structure by using simple welding on the site. Such integral joints have been proved to provide the mechanical performance better than assembled joints and to be very suitable for segmental construction of bridges [3,4]. In China, welded integral joints were first used in Sunkou Yellow River Bridge (1995) in Henan Province, and the newly constructed steel truss bridges adopting such joints typically include Guotai Bridge (2008) in Tianjin city, Chaotianmen Yangtze River Bridge (2009) in Chongqing city, Tianxingzhou Yangtze River Bridge (2009) in Hubei Province, Baling River Bridge (2009) in Guizhou Province, Minpu Bridge (2010) and Minpu Second Bridge (2010) in Shanghai city, Xinghai Bay Bridge (2015) in Liaoning Province, as well as Dashengguan Yangtze River Bridge (2011) and Hutong Yangtze River Bridge (under construction) in Jiangsu Province, etc.

For the steel trusses composed of rectangular or circular section tubes, concretes are usually filled in the chords with the aims of improving the rigidities and load bearing capacities of both structures and joints. In these concrete-filled steel trusses, the micro-expansive concretes are commonly poured into the hollow chords after the assemblage of members, and eventually the chords are full of concrete in most occasions. The advantages of such fully concrete-filled structures have been revealed by many researches. Packer [5] carried out the earliest tests for concrete-filled rectangular section connections where

* Corresponding author.
E-mail addresses: cheng_bin@sjtu.edu.cn (B. Cheng), xiangsheng1994@live.com (S. Xiang), zuo1799@sina.com (W. Zuo), ngteng@sjtu.edu.cn (N. Teng).

https://doi.org/10.1016/j.engstruct.2018.03.061
Received 14 July 2017; Received in revised form 10 March 2018; Accepted 20 March 2018
0141-0296/

significant improvements in strength were observed. Liu et al. [6,7] experimentally investigated the effects of concrete filled in chords of rectangular hollow section (RHS) and circular hollow section (CHS) steel tube truss, and concluded that the concrete filling in chord can not only help reinforcing the steel tubes but also enhance the rigidities and ultimate bearing capacities of both joints and whole trusses. They further presented the enhanced behaviors of a novel composite tubular truss bridge where the tubular joints were reinforced with concrete and perfobond leiste ribs [8]. Based on test results and simulation analyses, Zheng et al. [9] revealed the mechanical properties and failure modes of square hollow tube N-joints with grout-filled chords and then developed the formulae to predict the ultimate bearing capacities of such joints. Kim et al. [10] carried out the static test for a truss girder with lower chords of concrete filled rectangular steel box section to assess the effects of infilled concrete and revealed that the stresses in the chords have been significantly reduced. Xu et al. [11] focused on experimental behaviors of concrete-filled CHS connections and results showed that the infilled concrete makes significant contributions to the ultimate bearing capacities of connections. The behaviors of concrete-filled stainless steel tubular T- and X-joints with square and rectangular members were also investigated by Feng and Young [12,13], where the experimental results were compared with the strengths predicted by existing design rules. However, it has also been recognized that the on-site concrete pouring would most probably result in some unfilled spaces in long chords, especially when perforated inner stiffeners/diaphragms were provided in the chords. And on the other hand, remarkable self-weight of widely distributed concrete in chords could also raise the stress levels within the structure and then increase the steel used.

As for the truss bridges where welded box-section members and integral joints are used, the previous two problems regarding full concrete filling could be skillfully avoided by introducing the partial concrete filling scheme. More specifically, the concrete can be first poured into the hollow chords of integral joint segments that have been fabricated in the factory. Besides the designed stiffeners in the joint segments, some other diaphragms in the chords, either perforated or imperforated, could be employed for the convenience of concrete pouring. Then the concrete-filled integral joint segments and the hollow box-section member segments (including chord segments and brace segments) will be transported to the bridge site. Finally, all segments will be welded together on the site until the whole structure forms. Fig. 1 typically shows an assembled Warren truss bridge, where the pre-filled concretes exist only within the integral joint segments. In such partially concrete-filled truss, the concretes filled around the joint core zones are expected to improve the strengths of both joints and member ends, and the absence of concrete in other chord segments could keep the self-weight induced member forces and sectional stresses from being much higher than those of hollow truss. Moreover, unfilled spaces in concrete-filled regions are unlikely to happen since the concrete pouring distances are fairly short.

For the steel truss bridges with welded integral joints, it is segmental construction of truss which makes the partial concrete filling possible, and only the joint core zones where the stresses are of the highest have been reinforced by infilled concrete. The principals reflect the meaning of a Chinese idiom called "Good steel should be used in the blade". Actually, beside this, partial concrete filling has also been introduced to the steel bridge piers. Usami et al. [14,15] first carried out the cyclic and dynamic loading for the steel box columns where the bottoms have been partially filled with concrete. The inelastic behavior, ultimate strength and ductility of partially concrete-filled thin-walled steel bridge piers under the combined action of compression were further investigated by Mamaghani and Packer [16,17], followed by the development of a modified seismic design method considering the effects of residual stresses. Yuan et al. [18] also tested 20 square section specimens of partially concrete-filled steel bridge piers under bidirectional dynamic loading, and the results showed that the partial concrete filling can effectively improve the seismic resistance performance if the concrete inside the steel bridge piers is sufficient in quantity. Beyond that, there is no published literature regarding the previously mentioned partially concrete-filled integral joints in steel truss bridges.

This paper presents the structural behaviors of partially concrete-filled welded integral T-joints by using experimental and numerical methods. The studied T-shape joints are considered to be simply supported at chord ends. Two load cases, i.e., horizontal loading and vertical loading, are employed in the static tests. Behaviors such as elastic rigidities, failure modes, characteristic loads as well as characteristic displacements of the joints are thoroughly investigated. The influences of concrete filling length in the chord are comparatively analyzed. The optimal concrete filling lengths for the joints are finally suggested by considering both advantages and disadvantages of the concrete.

2. Test setup

2.1. Specimens

Six T-shape integral joints were manufactured for testing. The specimens were categorized into two groups according to the structural detailing of chord-to-brace corner, i.e., group A without arc transition and group B with arc transition. In each group, three cases of concrete filling in chord, that is, hollow chord (i.e., no concrete filling), partially concrete-filled chord (i.e., concrete filling length of 800 mm), and fully concrete-filled chord (i.e., concrete filling length of 1500 mm), were considered. The chord sections of the joints were 150 mm wide and 200 mm height, and the brace sections were 150 mm wide and 150 mm height. All specimens had the chords of 1500 mm long and the braces of 650 mm long, which means the member ends were kept away from the joint core zone by at least three times the members' sectional height so that the effects of boundary conditions could be ignored. The steel plates used for welding were of 8 mm thick. The sectional walls of members (i.e., webs and flanges of chords and braces) were welded together through 7 mm groove welds plus 7 mm fillet welds, while the diaphragms and the end plates were welded to the sectional walls by

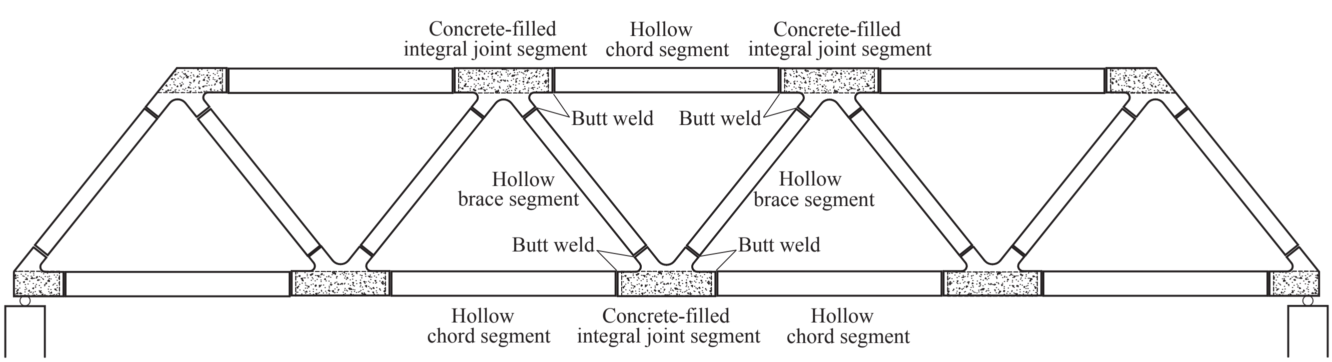

Fig. 1. Partially concrete-filled steel truss bridge.