Thin-Walled Structures 123 (2018) 409–419

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Prediction on ultimate strength of tube-gusset KT-joints stiffened by 1/4 ring plates through experimental and numerical study

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ARTICLE INFO

Keywords:
Tube-gusset joint
Ring plate
Ultimate strength
Failure mode
Design formula

ABSTRACT

One typical joint in steel tube tower, i.e. the tube-gusset KT-joints stiffened by 1/4 ring plates, has been paid attention lately due to its merits about reasonable stress distribution and low cost. But the relevant design theory lags obviously other than design recommendations from JSSC and CIDECT. However they are proved less effective with regard to certain failure mode. For this reason, the paper has proposed one design formula to make up the deficit based on yield line theory. Finally the proposed formula is testified to be more accurate and versatile than other design rules.

1. Introduction

Steel tube towers are increasingly used for transmission line construction due to their aesthetic appearance and good mechanical properties. Joint design is one of the main works of steel tube towers, and therefore, joint's property has drawn the attention of designers. The joints of steel tube towers can be divided into two types, i.e. tubular and tube-gusset joints. Tubular joints are made of circular hollow section (CHS) braces and chords. The CHS brace needs to be cut at the end to match the profile on the CHS chord perfectly prior to welding which significantly adds extra costs. Alternatively, the tubular joint can be replaced by the tube-gusset joint that enables the CHS brace and CHS chord connected by gusset plate. It can reduce the cost of structure manufacture significantly. For this reason, tube-gusset joints are increasingly broadly used in power transmission towers, especially in long-span transmission towers. However, to be noted, stress concentration often occurs in the chord face near both ends of the weld between the gusset and the chord resulting in a large regional deflection [1]. Naturally some researches get to think of adding a ring plate to stiffen this region that actually obtains a good effect [2]. Nevertheless, this type of joint hasn't received considerably applications in engineering, because it is relative brand-new and its theory is not maturational.

Correspondingly, the theory about the gusset-plate to CHS chord joint has been studied for over 30 years. The earliest study was carried out in Kumamoto University in 1984 [3]. A set of strength equations is proposed to calculate the ultimate strengths under axial load for gusset-plate to CHS tube joints. And then Ariyoshi and Makino [4] summarized the database of them and present equations for ultimate strength, yield strength and initial stiffness. But the former studies have not considered the combined effect of axial chord force and axial brace force. The eccentricity, in fact, cannot be neglected and it can arouse an extra moment. Hence, Kim [5] suggested a formula considering eccentric component force of axial brace force through parametric study. Afterward Wardenier et al. [6] investigated joints loaded by in-plane or out-of-plane bending. Based on the aforementioned research International Institute of Welding's Sub-commission (IIW-XV-E) and International Committee for the Development and Study of Tubular Structures (CIDECT) all draft design recommendations for gusset-plate to CHS tube joints [7,8].

As for the theory of joints stiffened by ring plates, there is not too much attention focused other than Japanese Society of Steel Construction (JSSC). In 1974, Japanese scholars have carried out a series of investigation on the strength of tube-gusset joints with and without stiffened plate [2]. On the basis, JSSC proposed a design formula of the tube-gusset joint stiffened by ring plates in 1995 [9], which is generally applied in Japan up to now. However, this specification has been shown conservative through experimental observation [10]. For example, China Power Engineering Consulting Group (CPECG) carried out a series of experiment investigations, and they found that the design formula in JSSC is quite conservative especially for some certain conditions [11]. Thus, it is necessary to explore more accurate design formulae and develop practical design code for these joints.

In this paper, we carry out experimental and numerical approaches to investigate the ultimate strength of the tube-gusset KT-joints stiffened by 1/4 ring plates, and then propose a set of design formulae that

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https://doi.org/10.1016/j.tws.2017.11.029
Received 28 April 2017; Received in revised form 13 November 2017; Accepted 14 November 2017
0263-8231/

Table 1
Measured dimensions of specimens.

Specimen	Chord member (mm)		Ring plate (mm)		Gusset plate (mm)
	D	*T*	*R*	t_r	*B*
Φ194 × 6-0 × 0	194.0	6.00	-	-	658
Φ356 × 8-0 × 0	356.0	8.02	-	-	788
Φ194 × 6-100 × 6	194.0	5.96	101.03	6.37	658
Φ194 × 6-80 × 8	194.1	6.11	79.73	7.33	658
Φ194 × 6-100 × 8	194.1	6.01	97.31	7.60	658
Φ194 × 6-40 × 10	194.0	6.67	40.05	9.90	658
Φ194 × 6-60 × 10	194.0	5.75	60.26	9.35	658
Φ356 × 8-72 × 8	356.0	7.87	72.37	7.43	788
Φ356 × 8-130 × 10	356.0	8.73	130.68	9.42	788
Φ194 × 6-60 × 6	194.1	6.13	58.64	5.69	658
Φ194 × 6-14 × 8	194.0	6.00	13.90	8.13	658
Φ356 × 8-60 × 10	356.1	7.98	60.86	9.50	788
Φ356 × 8-36 × 6	356.1	7.74	37.33	5.39	788
Φ356 × 8-60 × 6	356.0	7.90	62.75	5.58	788
Φ356 × 8-72 × 6	356.0	8.67	71.68	5.67	788
Φ356 × 8-48 × 8	356.0	8.10	52.04	7.65	788

can be used to predict the ultimate strength more effective and accurate than other traditional methods. The detail work is introduced as follows. In Section 2, experiment is developed to observe different failure modes and load-deformation relations of specimens so as to obtain their practical ultimate strengths. Then, Section 3 presents a simulation method through Finite Element (FE) method to imitate the same specimens, which is employed for geometric parameter analysis in Section 4. In Section 5, the ultimate strength results measured from experiment and FE method are taken to contrast with some current design specifications (CIDECT and JSSC). It is found these codes are not always effective at any conditions. On the basis, Section 6 proposes a practical design formula fitting for the KT-joints, which is verified to be much more accurate and versatile than other mentioned methods.

2. Experimental investigation

2.1. Specimens

We choose tube-gusset KT-joints stiffened by 1/4 ring plates (to be abbreviated as "KT-joints" in what follows) as specimens in experimental investigation because they are the most common type of joints in power transmission tower. There are 14 specimens altogether to be tested in this paper. All the specimens are fabricated with chord members, brace members, gusset plates, 1/4 ring plates and bolts (see Fig. 1). The chord is fully welded by the gusset plate that is connected to the brace members by series of bolts. In the experiment, we adopt two types (Φ194 × 6 and Φ356 × 8) for the chord members and one type (Φ95 × 6) for the brace members. The length of the chord members (*L*) is set as 2000 mm which is sufficiently long so as to avoid the coupling effect between the concentrated forces aroused by the locations of ring

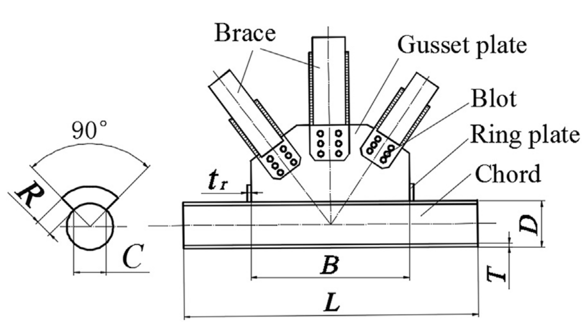

Fig. 1. Definition of symbols for KT-joints.

Table 2
Material properties of chord member and ring plate.

Component	Type	Yield stress σ (MPa)	Elastic modulus *E* (GPa)	Poisson ratio *ν*
Chord	Φ194 × 6	363.33	197.82	0.228
	Φ356 × 8	360.80	230.11	0.426
Ring plate	t_r = 6	334.66	188.77	0.395
	t_r = 8	291.72	178.62	0.394
	t_r = 10	315.18	202.50	0.391

plate and the fixed ends. As well, the brace members have length from 500 mm to 900 mm to avoid overall buckling. As for the ring plates, the width (*R*) is set from 14 mm to 130 mm and thickness (t_r) from 6 mm to 10 mm. Two specimens without stiffeners are also included. The measured dimensions of all the specimens are shown in Table 1. For example, "Φ194 × 6-60 × 6," means the chord with diameter of 94 mm and thickness of 6 mm, and the ring plate with width of 60 mm and thickness of 6 mm. In addition, "Φ194 × 6-0 × 0″ and "Φ356 × 8-0 × 0″ represent the two KT-joints without ring plates, severally.

The strength of the welding materials used for the 1/4 ring and gusset plates is set to be the same as that of the chord. The material properties of the chord members and ring plates are determined by tensile coupon tests and the results are summarized in Table 2. Fig. 2 has shown the measured stress-strain curves of chord members and ring plates.

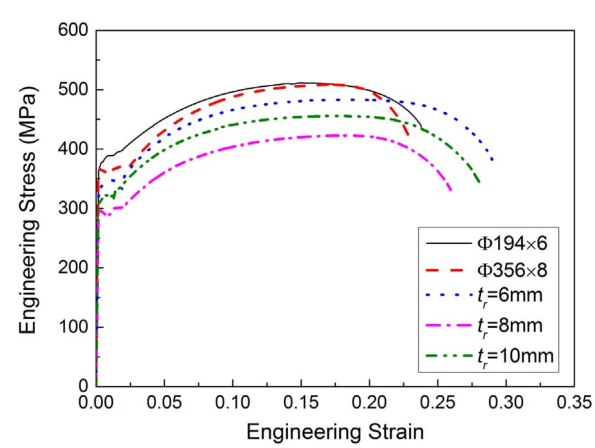

Fig. 2. The measured stress-strain curves.