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Experimental and theoretical studies on the stability of steel tube–coupler scaffolds with different connection joints

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ABSTRACT

This paper presents a systematic experimental and analytical study on the stability behavior of steel tube–coupler scaffolds (STCSs), wherein upper horizontal tubes transfer construction loads. Four specimens with common geometric sizes were constructed and tested statically in the lab to obtain the strength and failure modes. Advanced nonlinear finite element analysis, which considers the initial member imperfection and semi-rigid behavior of right-angle couplers, was conducted on the specimen models by using ANSYS to obtain the stress distribution, strength, and failure modes of the STCS. Analysis results were compared with the experimental results. The following can be concluded from the experimental and analytical results. (1) The main failure mode of the STCSs is the local instability of a vertical steel tube if the upper layer joints have sufficient anti-slipping capacity. Otherwise, the main failure mode is the slipping and fracture of right-angle couplers. (2) The strength of STCSs is sensitive to upper joint type. The load capacity of ST2 with the strengthened joint is 1.30 times that of ST1 with a common joint, and the load capacity of ST4 with a common joint is 1.16 times that of ST3 with a weak joint. (3) The numerical simulation method presented in this paper is generally consistent with the full-scale test results and has a maximum difference of 11.08%.

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1. Introduction

Many steel scaffold systems, such as door-type scaffolds (Fig. 1(a)), inserting-type scaffolds (Fig. 1(b)), cuplok-type scaffolds (Fig. 1(c)), and steel tube–coupler scaffolds (STCSs) (Fig. 1(d)), are commonly used as temporary structures to support workers, materials, and structural members during construction. The STCS system is the most popular system in China, United Kingdom, and several other countries because of its easy fabrication, installation, and dissemination. In the past, these systems usually fail in construction sites because of inadequate design, poor installation, and overloading, thus causing not only project delays but also serious injuries and casualties to construction workers [1,2]. A picture of a steel scaffold collapse is shown in Fig. 2.

Many studies have been conducted on scaffolds in the last 15 years because of the injuries and casualties induced by scaffold failure in construction sites. Chan et al. [1], Peng et al. [2–6], Yu [7], and Weesner [8] produced many studies on the stability capacity and design method of door-type scaffolds experimentally and theoretically. Pienko [9] determined the capacity of the key joint in inserting-type scaffolds on the basis of numerical analysis and by considering nonlinear materials and the interaction between particular joint elements. Peng et al. [10] investigated the load capacities and failure modes of inserting-type scaffolds on the basis of experimental tests supplemented by analyses. Zhang [11–13] conducted research on cuplok-type scaffolds by using the probability-based design method. Beale [14–16], Ao [17], Yue [18], and Liu [19,20] conducted systematic studies on stability capacity and design method of STCSs.

Two common force transfer paths are usually used for STCSs during construction, as shown in Fig. 3: one is the load transfer to the vertical members directly through the U-heads (Fig. 3(a)); the other is the load transfer to the vertical members by the top horizontal members (Fig. 3(b)). Many experimental and analytical studies have been conducted for the first type [14–20]. However, few studies have been performed for the second type, which is used in the construction of large-span spatial structures such as gymnasiums, train stations, garages, and bridges.

Many disastrous collapses of STCSs have occurred in several countries. Thus, the safety of this type of system during construction has come into question. Moreover, structural properties using

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(a) Door-type Scaffolds (b) Inserting-type scaffold

(c) Cuplok-type Scaffold (d) Steel Tube–Coupler Scaffold

Fig. 1. Four types of scaffolds.

the second force transfer path are relatively complicated because of the semi-rigid nature of the coupler and the lack of rational design guidelines in the national standards for STCSs in China [21], the European Union [22,23], the United States [24], and Japan [25]. Consequently, understanding the structural behavior of STCSs through experimental studies and proposing rational design recommendations is important.

2. Rotational stiffness and slipping stiffness of right-angle coupler

The STCS mainly includes three types of members: vertical members, horizontal members, and X-bracing members. The right-angle coupler is used to connect the vertical member to the horizontal member (Fig. 4(a)), and the rotational coupler is used to connect the X-bracing member to the vertical member (Fig. 4(b)). The mechanical property of a right-angle coupler has a significant effect on the load bearing of STCS. Therefore, the rotational stiffness and slipping stiffness of the right-angle coupler were studied through experiments.

Fig. 2. Collapse of steel scaffold during construction in Anhui Province, November 3, 2011.

The tightening torque of the right-angle coupler has a significant effect on its mechanical property, and the "technical code for safety of steel tubular scaffold with couplers in construction (JGJ 130-2011)" requires such torques to be approximately 40 N m. Therefore, the rotational stiffness and slipping stiffness of the right-angle coupler were studied only with a 40 N m tightening torque.

Abdel-Jaber have carried out a systematical research on the rotational strength and stiffness of connectors of STCS, and the slipping stiffness was not included [26]. Considering the material differences, the rotational stiffness and slipping stiffness of the right-angle coupler were studied in this paper.

2.1. Test setup and loading procedure

Two specimens with a tightening torque of 40 N m were tested to obtain the rotational stiffness of right-angle couplers. The test setup is shown in Fig. 5. To eliminate the influence of elastic deformation of vertical member and horizontal member, the dial indicators were set 200 mm away from the right-coupler, as shown in Fig. 5. The moment was loaded from 0 to 900 N m with an increment of 100 N m. Weights were used as load. In Fig. 5, "1" represents the horizontal members, "2" represents the vertical members, and "3" represents the right-angle coupler. The unit is millimeter.

Two joint types were usually used in construction as shown in Fig. 6. The first type uses two right-angle couplers (Fig. 6(a)), and the second type uses three right-angle couplers (Fig. 6(b)). Three

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