Journal of Constructional Steel Research 138 (2017) 806–822

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Mechanical behaviors of the Assembled Hub (AH) joints subjected to bending moment

Qinghua Han [a,b], Yiming Liu [b], Jinyuan Zhang [b,c], Ying Xu [a,b,]*

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[b] School of Civil Engineering, Tianjin University, Tianjin 300072, China
[c] Key Laboratory of Coast Civil Structure and Safety of Ministry of Education, Tianjin University, Tianjin 300072, China

ARTICLE INFO

Article history:
Received 15 June 2017
Received in revised form 21 August 2017
Accepted 23 August 2017
Available online xxxx

Keywords:
Assembled Hub joint
Stiffness characteristics
Bearing capacities
Bending moment
Component method
Stiffener

ABSTRACT

To satisfy the demand for assembled construction of single-layer reticulated domes, a novel Assembled Hub (AH) joint with good mechanical performance and economic benefit is introduced in this paper. Two available connection types are developed to satisfy different engineering requirements. The theoretical solutions of the elastic stiffness and the bearing capacity of the new joint system are proposed based on the component method. A series of bending tests were conducted to investigate the failure mechanism of AH joints, and the FE analysis was carried out to simulate and verify the mechanical behaviors of AH joints. Finally, the strengthening effects of two kinds of stiffeners are carefully compared and discussed. The results indicate that the AH joints type I show excellent ductility in the loading process. The failure of joints is caused by the plastic instability of the hub or the excessive plastic deformation of the closure plate. The plastic moment resistance of joint is determined by the thickness, height, outer diameter and material of the hub, as well as the bolts pitch. By contract, the AH joints type II display lower ductility but higher bearing capacities in the loading process. The failure mode is the connection failure. The ring stiffeners have a better strengthening effect than the radial stiffeners. A comparison between the computations and the experiments highlights the validity of the suggested bearing capacity formulas, which can be further used to guide the joint design.

1. Introduction

For single-layer reticulated domes, the mechanical behavior of the joints is the determining factor for the structural safety. Currently, the common joints used in the reticulated domes can be divided into two categories, the welded joints and the assembly-type joints. The traditional welded joints, such as the welded hollow spherical joints [1] and tubular joints [2] have good mechanical properties but may suffer from the problems of residual welding stress and high labor costs. The traditional assembly-type joints include the Mero joints [3–4], Temcor joints [5–6], socket joints [7–8] and Triodetic joints [9] etc. However, the Temcor joints are mainly used for connecting structural members with open cross-sections. The Mero joints, socket joints and Triodetic joints may have the problem of insufficient rotational stiffness, and therefore not suitable for the single-layer reticulated domes. Moreover, most of them are used for connecting circular-section or I section members, but few of them are applicable to connect with rectangular section members.

Thereafter, some new assembly-type joints such as the Bolt-column joints [10] and the Ring-sleeve joints [11] were further proposed, in which the column nodes or the rings were connected with the rectangular members with bolts. It is worth mentioning that, both the column nodes and the rings were considered as rigid bodies in the previous analysis. Therefore, the bearing capacities of the above joints are decided by the strength of the connections instead of the central areas of the joints.

Previous studies indicate that the stiffness characteristics of joints may have a considerable effect on the stability and the failure mode of space structures [12]. Therefore, great efforts were made to evaluate the effect of joint stiffness on the responses of the reticulated domes. Kato et al. pointed out that the joint stiffness has a greater effect than the imperfection sensitivity in the elasto-plastic stability analysis of domes [13–14]. López proposed a new formula, which allows designers a rapid estimation of the buckling loads for semi-rigid jointed single-layer latticed domes [15–16]. Han et al. developed a mechanical model considering the stiffness degeneration of the welded spherical joints, which could be used to assess the effect of joint stiffness on the stability bearing capacity of single-layer reticulated domes [17]. Fan et al. presented a classification system based on the joint stiffness. All the joints in lattice shells can be classified as rigid joints, semi-rigid joints or pinned joints according to the classification system [18]. However,

* Corresponding author at: State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China.
E-mail address: yingxu_civil@tju.edu.cn (Y. Xu).

http://dx.doi.org/10.1016/j.jcsr.2017.08.026
0143-974X/

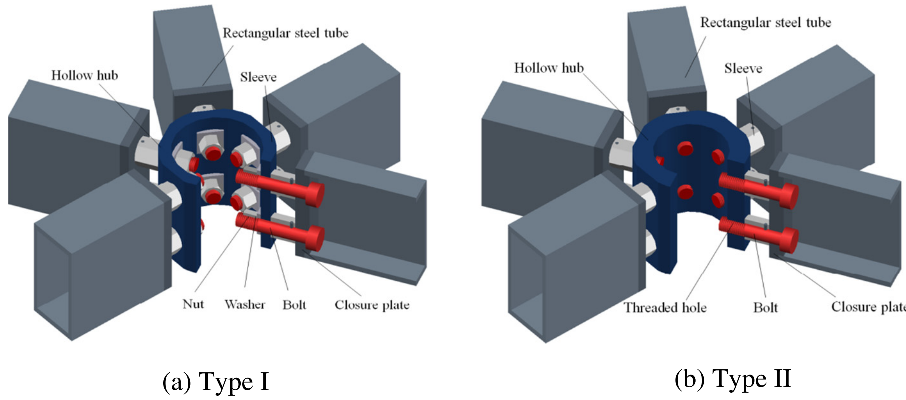

Fig. 1. Configurations of the AH joints.

almost all the existing semi-rigid joints have the problem of low rotational stiffness, which may result in the significant reduction of the stability bearing capacities of the reticulated domes.

In view of the above problems, a novel AH joint with good mechanical performance and economic benefit is proposed in this paper. Firstly, the theoretical solutions of the elastic stiffness and the plastic moment resistances of the new joint system are derived based on the component method. The mechanical behavior of the hub is described in detail, which was usually regarded as the rigid body in the previous study [9–11]. A series of bending tests were carried out to investigate the failure mechanism of AH joints, and the FE analysis was carried out to simulate and verify the mechanical behavior of AH joints. Finally, two kinds of stiffeners are carefully compared and discussed. The design method of AH joints is also proposed based on the above analysis.

2. Brief introduction of the AH joints

2.1. Classification of the AH joints

As shown in Fig. 1, the AH joint system is mainly composed of a hollow hub, with bolts, sleeves, closure plates and the connecting members. The hollow hub is made from thick-walled seamless steel tube, and the outer side is cut as a hexagon to connect tightly with the sleeves. The closure plates are welded to the ends of the steel tubes in the factory. The bolts and the sleeves are used to connect the closure plates with the hollow hub. Two types of connections are designed to satisfy different engineering requirements. Nuts and washers are required in AH joints type I, in which the hubs have relatively large diameter-thickness ratios. The bolts are fastened by nuts and sleeves at the construction site. Conversely, The bolts in AH joints type II are screwed into the threaded holes. As a result, the depth of the threaded holes should be larger than 1.3 times the nominal diameter of the bolts to ensure the connection strength, and the hubs have relatively smaller diameter-thickness ratios.

2.2. Failure characteristics of the AH joints

The typical moment-rotation curves of an AH joint are shown in Fig. 2. In the elastic stage, the rotation of the joint is linear with the bending moment, and the elastic stiffness of the joint is defined as K_M. The elastic bearing capacity of joint at the end of the elastic stage is defined as M_E [17]. In the elastio-plastic stage, the inner and outer surfaces of the hub start to yield [19], the stiffness of joint declines and plastic hinges form gradually on the hub. The closure plates, the sleeves and the bolts may also yield in this stage. The plastic bearing capacity is defined as M_P when the yield lines form completely on the hub. M_P can be

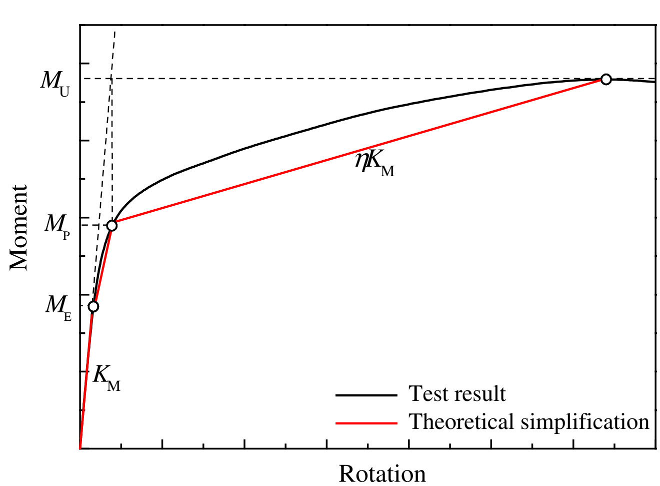

Fig. 2. Moment-rotation curves of the AH joint (Type I).

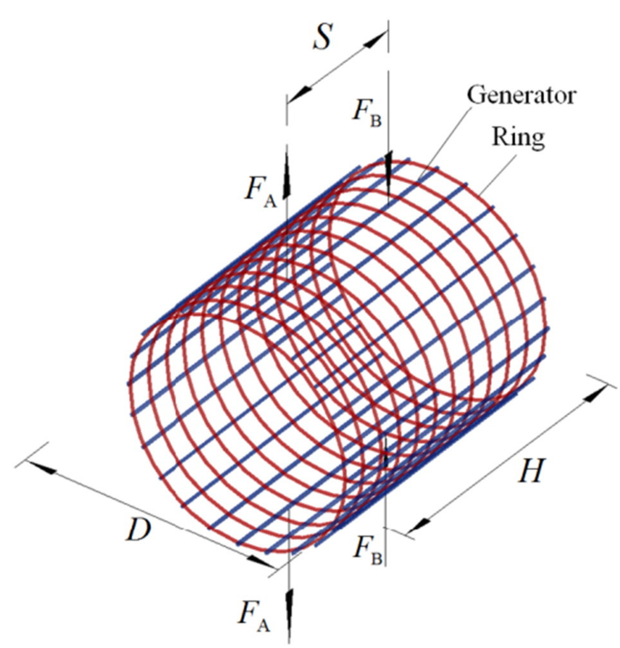

Fig. 3. Ring-generator model.