C型节点力学性能及其半刚性网壳稳定性研究

Research on mechanical performance of bolt-column joint and stability of its semi-rigid reticulated shell

Introduction

With the advancement of modern construction techniques and electronic computing, single-layer reticulated shell has become widely utilized in iconic structures such as stadiums, terminals, and exhibition halls due to its exceptional efficiency, reasonable load distribution, cost-effectiveness, and visually appealing design. However, its application is constrained by the assumption of either pinned or rigid joints, which does not conform to the reality that most joints in spatial structures exhibit semi-rigid behavior lying between the two extremes.

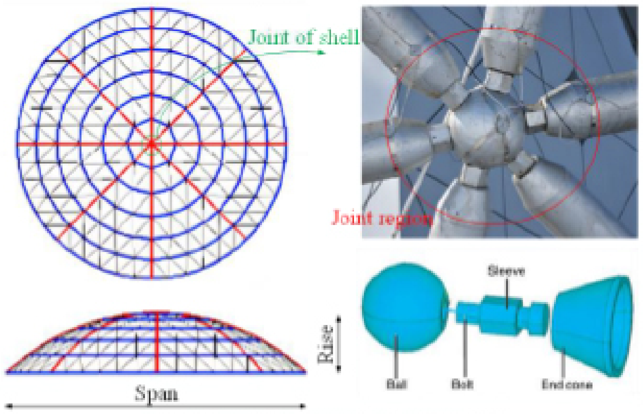

Fig. 1. Basic parameters of single-layer reticulated shell.
(Taking single-layer reticulated dome and bolt-ball joint as instance)

Previous researches have predominantly focused on effect of strong-axis bending stiffness of joint on stability of reticulated shell. In reality, reticulated shells exhibit varying sensitivity to different types of joint stiffness, in which few scholars have explored in depth. This study proposes an innovative modification to the OBC (original bolt-column) joint by incorporating a single web, two flanges, and two additional bolts, and this enhanced design is referred to as the IBC (improved bolt-column) joint. The mechanical behaviors of IBC joints under various loading conditions are determined, and a practical analytical model of IBC joint is developed. Afterwards, based on the load-displacement and moment-rotation curves of IBC joint obtained from numerical simulation, the effect of different joint stiffness on the load-carrying of single-layer cylindrical reticulated shells is figured out. Ultimately, the law in critical load and failure mode of shells considering all stiffness of IBC joint is presented.

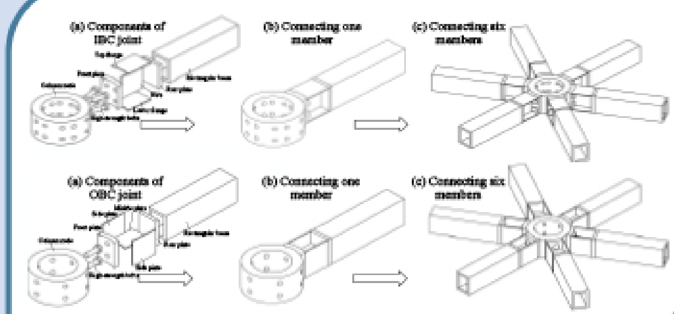

Fig. 2. Configuration of OBC and IBC joints.

Strong axis bending performance of joint has significant role on load-carrying capacity of single-layer reticulated shell. However, upon examining the cross section of cone part in Fig. 3, it can be observed that the moment of inertia of cone is insufficient to withstand significant bending moments. Consequently, OBC joint can be further improved for structural performance in cone head design.

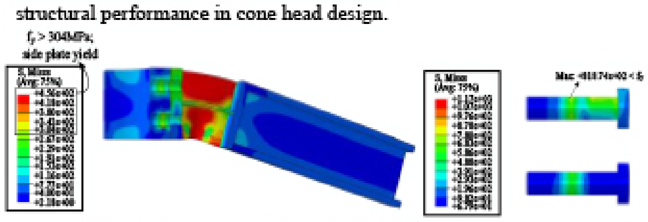

Fig. 3. Mises stress contour diagram of original BC joint at failure stage.

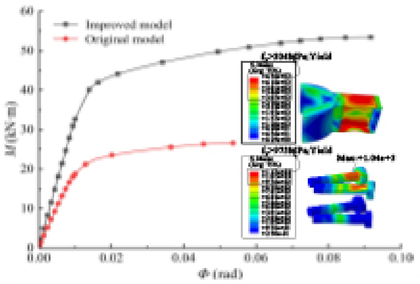

Fig. 3. Moment-rotation curves of OBC and IBC joints under pure bending about strong axis.

Practical analytical model for IBC joint under strong axis bending

A three-parameter power model (as shown in Eq. (1)) is developed to predict the moment-rotation relationship of IBC joint under pure strong axis bending, using initial stiffness K_j, ultimate moment M_u and shape parameter n.

$$M = \frac{K_j \phi}{[1+(\frac{\phi}{M_u/K_j})^n]^{1/n}} \tag{1}$$

- Initial stiffness K_j

The IBC joint is simplified as a spring model, as illustrated in Fig. 4. K_j can be derived from Eqs. (2).

$$K_j = \gamma_{p,k}\frac{M}{\phi} = \frac{\gamma_{p,k}F_b d_b}{\frac{2F_b}{d_b k_b}+\frac{2F_f}{d_f k_f}} = \frac{\gamma_{p,k}F_b d_b}{\frac{2F_b}{d_b k_b}+\frac{2F_b}{d_f^2 k_f}} = \frac{\gamma_{p,k} d_b}{2(\frac{1}{d_b k_b}+\frac{1}{d_f^2 k_f})} \tag{2}$$

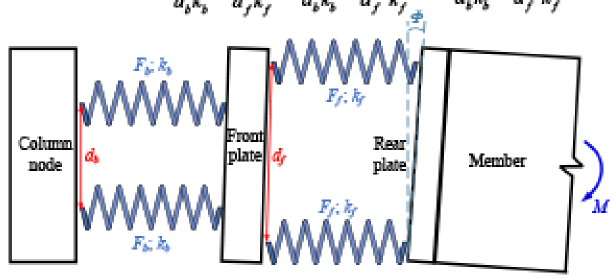

Fig. 4. Spring model of IBC joint.

- Ultimate moment M_u

The ultimate moment Mu of the joint for the first failure mode in Fig. 5 can be mathematically expressed as

$$M_u = f_{uf} A_f d_f \tag{3}$$

Regarding the second failure mode, the equation below provides M_u.

$$M_u = \frac{2 f_{ub} A_b d_f D_b \cos\theta}{d_f - d_b - D_b} \tag{4}$$

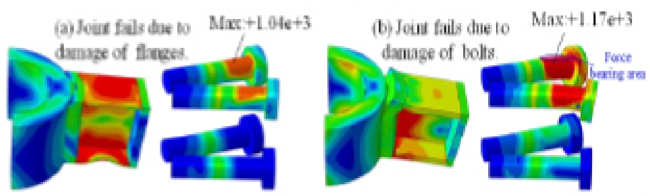

Fig. 5. Failure modes of IBC joint. (unit: MPa)

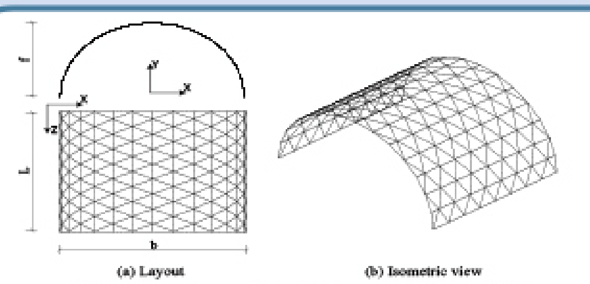

Fig. 6. Illustrative diagram of the single-layer cylindrical reticulated shell.

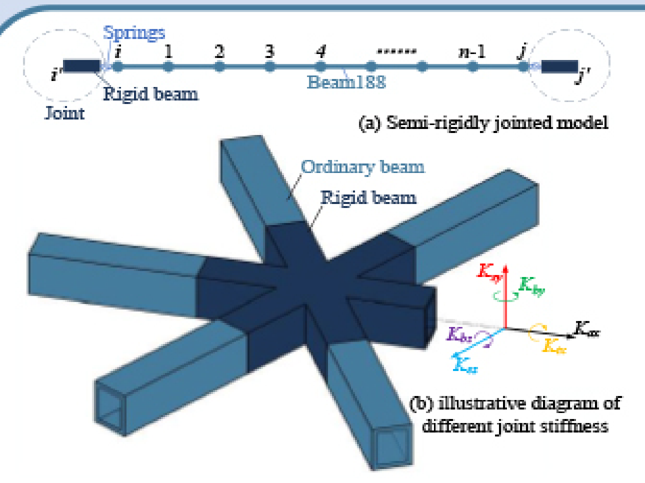

Fig. 7. Semi-rigid mechanical model.

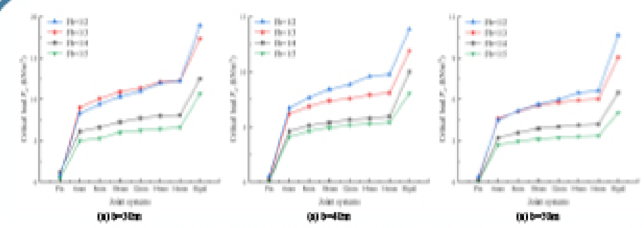

Fig. 8. Critical loads of shells considering all stiffness of IBC joint.

Conclusion

(1) IBC joint exhibits a significant improvement in strong axis bending performance compared to OBC joint.

(2) All kinds of joint stiffness are enhanced in different levels with the increase of flange thickness. In addition, the bending capacity of IBC joint experiences a slight decrease or even an increase when subjected to a relatively small axial force.

(3) The proposed analytical model effectively captures the moment-rotation relationships of IBC joint at a high level of accuracy.

(4) The rules in load-carrying capacity are differently influenced by varying stiffness of IBC joint.

Acknowledgement

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Achievements

[1] Zhicheng XIAO, Ren LI, Huijun LI*, Shaozhong BI, Baohui LI. Effect of joint stiffness on the load-carrying capacity of single-layer cylindrical reticulated shell with improved bolt-column (IBC) Joint [J]. Thin-Walled Structures, 2024, 198: 111691. (DOI: 10.1016/j.tws.2024.111691) (SCI，中科院大类一区TOP，IF= 6.4)

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Teammates

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