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A Review on Seismic Performance of Blind Bolted Beam-Column Joints

Tingyu Guo¹, Dan Zhang², Chao Li¹, Xianle Sun¹, Ling Liu¹

Student, College of Civil Engineering, Hunan City University, Yiyang, China¹

Lecturer, College of Civil Engineering, Hunan City University, Yiyang, China²

ABSTRACT: High-strength bolts are widely used in steel beam-column connections, but traditional high-strength bolts are difficult to apply to steel tube columns because they require two-sided operations. The new type of blind bolts can realize unilateral installation and unilateral locking, which solves the problem of connecting closed-section columns and steel beams. However, there are few studies on the seismic performance of high-strength blind bolted joints at present. Therefore, this paper reviews the seismic performance of blind bolted joints and summarizes the influence of blind bolted connections on the mechanical properties of joints.

KEYWORDS: Blind bolts, Steel tube columns, Beam-column joints, Seismic performance.

I. INTRODUCTION

The cross-section of rectangular steel tube column is closed and biaxially symmetrical, and it has good bending and torsional stiffness, so it is easy to realize standardized production and assembly. The common forms of connections between rectangular steel tube columns and steel beams are inner diaphragm joints, cross-through diaphragm joints and outer ring plate joints. When using traditional high-strength bolt connection, it is necessary to open temporary installation holes on the wall of the steel tube column to tighten the nuts, and then repair the installation holes. The cutting and repair welding of the temporary installation holes not only affect the integrity of the steel tube column wall, but also require on-site welding operations. Therefore, how to improve the node connection method has received extensive attention from researchers at home and abroad.

With the continuous research and development of new fasteners, blind bolts can realize the functions of unilateral installation and unilateral tightening, without additional processing of installation holes, and the on-site construction is simple and convenient, which is very suitable for the connection of steel tube structures. However, the research and development field of blind bolt products started relatively late, and the research mainly focuses on the unilateral fastening mechanism of bolts, while the failure mechanism, bearing capacity and energy consumption analysis of blind bolted beam-column joints are still insufficient. It is very important whether the blind bolts can replace ordinary high-strength bolts in steel structure joints. Therefore, it is necessary to study the seismic performance of blind bolted beam-column joints further.

Paper is organized as follows. Section II describes the types of blind bolts, as well as the application of blind bolts in different joints, and summarizes the seismic performance of different blind bolted joints. Section III presents conclusion.

II. LITERATURE REVIEW

Since the 1990s, Europe and Japan have successively developed blind bolt products, which are special bolts that can be tightened and fixed with a wrench or other installation tools on one side, and can be used for structures such as closed sections or walls.

(1) Types and mechanical properties of blind bolts

At present, the blind bolts applied to the square steel tube column-H-shaped steel beam mainly include unilateral locking high-strength bolts and threaded anchoring unilateral bolts.

Pitrakkos et al. (2021) studied the resistance of Extended Hollo bolt (EHB) by simultaneously applying monotonic tension and shear forces. The obtained ultimate loads were used to model the tension-shear interaction diagram, and the effect of changing the tension-shear ratio on bolt performance was discussed. Based on the experimental data, a new interaction model was proposed.

Cabrera et al. (2021) conducted a critical review of related work on EHB, described the loading procedure used for testing and the resulting failure modes, listed the parameters evaluated and their respective applicability, and summarized the analysis model developed for EHB components. The analysis shows that the concrete strength has the greatest influence on the stiffness and strength of the column and the stiffness of the bolt, while the bolt grade has a great influence on the strength of the bolt.

Suo et al. (2020) carried out static loading tests on the extended end-plate connecting joints of three square rectangular steel tube columns and H-shaped steel beams, in order to study the mechanical properties of the new self-tightening high-strength blind bolt connection joints. The results show that the initial rotational stiffness of the blind bolted joint is lower than that of the M20 bolted joint, and the rotation angle is greater than 0.03 rad. The stress distribution pattern of bolt group is similar to that of traditional high-strength bolt group, and the neutralization axis is located near the center of bolt group. However, there are some defects in the design of the connection between the bolt anchoring sleeve and the screw tail, which leads to stress concentration and failure.

Jiang et al. (2021) improved the existing non-standardized sleeve high strength blind bolt, proposed standardized sleeve high strength blind bolt and small diameter blind bolt, and conducted tensile tests on bolts of grade 8.8 and 10.9 with diameters of 12mm, 16mm and 20mm respectively. By adjusting the installation torque, the separation load of the steel plate under different torques of each blind bolt was obtained, and the relationship between the pre-tension and the separation load of the steel plate and the stiffness of two stages was determined by deducing the formula. According to the above results, the recommended installation torque and pre-tension of the blind bolt were given. The analysis shows that the bearing capacity of the blind bolt is equivalent to that of the high-strength bolt of the same grade, and its stiffness is lower than that of the high-strength bolt, which has little influence on the rotational stiffness of the joint.

Zhou et al. (2021) set up threaded bolt holes on the steel tube column wall and the built-in H-shaped steel flange to replace the nuts of the high-strength bolt in the traditional beam-column end-plate connections. By tightening the high-strength bolt directly to the threaded hole, the unilateral connection of steel tube column-steel beam joint can be realized and the installation process can be simplified. The failure mode and bearing capacity of steel tube column-steel beam joints with thread-anchored blind bolt end-plate connections were studied by finite element method. The results show that the thread in the bolt hole on the built-in H-shaped steel flange plate increases the anchoring of the bolt hole to the high-strength bolt, and effectively avoids the bolt pull-out damage of the joint. When the thickness of the steel plate is greater than the bolt diameter, the threaded hole can provide sufficient anchoring force to the high-strength bolt, the joint failure mode is mainly end plate failure and high-strength bolt failure.

(2) Seismic performance of steel hollow tube joints with blind bolts

Scholars at home and abroad have discussed the application of blind bolts in steel tube column joints.

Jia et al. (2020) studied the seismic performance index of blind bolted connections between rectangular steel tube columns and H-shaped steel beams, compared the difference of seismic performance between blind high-strength bolts and conventional high-strength bolts, and put forward the restoring force model of joints. The results show that the slip phenomenon occurs in all the blind high-strength bolts, the hysteretic curve of the joint specimen is inverse S-shaped, the initial rotational stiffness of the specimen is about 70% of that of the conventional high-strength bolted joint, and the ultimate rotation angle of the specimen is 0.06-0.08 rad. The flexural bearing capacity of the joint is basically consistent with that of the conventional high-strength bolted joint, and its energy dissipation and ductility are lower than those of the conventional high-strength bolted joint.

Cho et al. (2019) evaluated the performance of the modular system of blind bolted steel frame and its beam-column joints through tests and analysis. The design of the new modular system made the strength of its beam members much lower than that of its column members, in order to realize the concept of strong column and weak beam. A simplified

analysis model of modular beam-column connection was proposed, its objectivity was verified by push-over analysis, and the results were compared with the test results.

Li et al. (2021) have carried out an experimental study on the connection between blind bolted T-shaped tube made of stainless steel and square hollow section (SHS). The effects of key parameters such as bolt type, bolt arrangement, wall thickness and specimen shape on the performance of T-to-SHS connection and members were determined. The design formulas for estimating the bearing capacity of T-tube and SHSs were put forward, which were in good agreement with the experimental results.

(3) Seismic performance of concrete filled steel tube (CFST) joints with blind bolts

In order to reduce the deformation of the column wall under the tension action of the blind bolt, **Zhao et al. (2021)** suggested the use of CFST columns. The extended end plate connection is a common form of beam-column connection in CFST structures. Based on the component method, a calculation model for the initial rotational stiffness of the CFST column-steel beam extended end plate connection joint was established. The through bolts or blind bolts were used as anchorage components of the joint. The influencing factors of the initial rotational stiffness of the joint were analyzed, the results show that the initial rotational stiffness of the joint can be effectively improved by appropriately increasing the thickness of the end plate. The improvement of initial rotational stiffness of joints with increasing the bolt diameter, the thickness of the steel tube, and the concrete grade is not significant as increasing the end-plate thickness.

Zhao et al. (2021) proposed a calculation method for the ultimate bending moment of the joints in order to predict the moment-rotation relationship of the CFST joints connected by flush end plates and blind bolts. Based on the component method, the analysis model of the initial rotational stiffness of the joints was established, and the ultimate moment and initial rotational stiffness of the joints can be predicted only by the structural size and material characteristics.

End plate blind bolt connection is a common type of concrete filled circular steel tube (CFCST) structure. **Fan et al. (2021)** proposed a determination method for predicting the ultimate bending moment. A calculation model based on component method was established. The proposed model can avoid extensive experiments and numerical simulations, since only the configuration and material properties are needed to obtain the required parameters.

In order to reveal the mechanical performance and failure mechanism of blind bolted end-plate connections between the square concrete-filled double skin steel tubular (CFDST) columns and steel-concrete composite beam, **Wang et al. (2020)** evaluated the failure modes and hysteretic curves by numerical analysis and low cycle reciprocating loads. The research shows that the joints of the CFDST columns and steel-concrete composite beam have good seismic performance and mechanical performance, and can be applied to prefabricated composite frames in high-intensity seismic areas. The numerical analysis method of this type of composite joints can be used for the design and calculation of prefabricated composite frames.

On this basis, **Zhang et al. (2022)** compared and analyzed the seismic performance of blind bolted T-shaped joints and through-bolted joints. The results show that the hysteretic curves of the joints are full and the energy dissipation capacity is strong. The blind bolts can take advantage of the unilateral locking of the inner steel tube of the double-type CFST column. The inner steel tube has a large strain value, but there is no obvious deformation in the node domain, and the joint force transmission is reliable and the structural integrity is good. Compared with the through-bolted joints, the initial stiffness of the blind bolted joints is smaller, the ultimate bearing capacity is increased, and the deformation capacity and ductility of the joints are significantly improved, indicating that the blind bolted connections can better ensure the stability and seismic resistance of the joints.

Guo et al. (2019) studied the seismic performance and analytical model of CFDST column blind-bolted flush or extended end-plate connections. The test shows that the blind bolted connections of the CFST column have an obvious limiting effect on the outward deformation of the column wall. The blind-bolted flush or extended end-plate connections of circular CFDST columns have superior seismic performance and can meet the design requirements of high-intensity seismic areas.

Li et al. (2016) used ABAQUS to discuss the influence laws of moment-rotation curves of CFST column-steel beam blind bolted joints. The results show that welding channel steel outside the core area of the joints or built-in short H-

shaped steel can significantly improve the flexural capacity of the joints. The reinforced blind-bolted joints are semi-rigid connections or partial strength joints. The flexural bearing capacity of the joints can be improved with the increase of the thickness or the strength of the channel steel, the similar effect can be achieved by increasing the thickness or the strength of inner H steel.

Mahmood et al. (2021) assumed that member strength was provided by steel hollow section plate bending and anchoring. Based on the yield line theory, the strength model of steel hollow section plate was established. The anchoring strength was considered to be equivalent to the load required to initiate failure of the concrete cone. An elastic spring was used to establish the stiffness model of the member. The overall bending behavior of the member was represented by a quadrilinear model. This model can be generalized to other similar blind bolted connections.

Wang et al. (2017) studied the structural properties and failure modes of blind bolted flush or extended end-plate composite joints through experiments and numerical analysis. The effects of various parameters on the moment-carrying capacity and rotational stiffness of composite joints under positive or negative bending moments were also studied. The test results show that all specimens exhibit good strength and stiffness, and have large deformation capacity.

Wang et al. (2017) studied the seismic performance and dynamic response of semi-rigid composite joints composed of composite beams and thin-walled CFST columns connected by blind bolts. The test results show that the structural response of the test joints under seismic action is consistent with the expected performance of the analysis at different damage levels. Combined joints have good energy dissipation and seismic performance, and can provide sufficient ductility and strength to meet seismic design requirements.

III. CONCLUSION

In conclusion, compared with the high-strength bolted joints and through-bolt joints of the same grade, the initial stiffness of the blind bolted joints is smaller, the ultimate bearing capacity is improved, and the deformation capacity and ductility of the joints are significantly improved, indicating that the blind bolted assembly connection can better ensure the stability and earthquake resistance of the joints. The concrete strength has the greatest influence on the stiffness and strength of the column member and the stiffness of the bolt member. Properly increasing the thickness of the end plate can effectively improve the initial rotational stiffness of the blind bolted joints.

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