

Article

Experimental Investigation of Tensile Behavior of One-Side-Bolted T-Stub Connections

Yanting Zhuang¹, Tao Qin², Yuan Liao², Hengli Cai^{3,*}  and Shujun Hu^{2,*} 

¹ College of Intelligent Construction Engineering, Minnan University of Science and Technology, Quanzhou 362700, China; zhuangyanting123@163.com

² School of Infrastructure Engineering, Nanchang University, Nanchang 330031, China; 402500230019@email.ncu.edu.cn (T.Q.); liaoyuan@email.ncu.edu.cn (Y.L.)

³ School of Civil and Architectural Engineering, Jiangxi University of Water Resources and Electric Power, Nanchang 330031, China

* Correspondence: caihengli@juwp.edu.cn (H.C.); hushujun@ncu.edu.cn (S.H.)

Abstract

In this paper, an innovative T-stub connection with square-neck one-side bolts (TS-SNUBC) is developed to improve the bearing capacity and construction reliability of the box column-H beam joint. Twelve T-stub specimens, considering variations in bolt type, flange thickness, and bolt hole orientation, were designed and tested under uniaxial tension. The failure modes, load–displacement responses, ultimate load-bearing capacities, and key quantitative mechanical indicators (initial stiffness, ductility index and cumulative energy dissipation) of the specimens were evaluated. The results indicate that all specimens failed due to the yielding of the thin flange. Specimens with conventional bolts demonstrated the highest load-bearing capacity, followed by those with TS-SNUBC and then slotted one-side bolts. Increasing the thin flange thickness significantly improved the ultimate bearing capacity of the TS-SNUBC specimens. Notably, TS-SNUBC specimens with thin flange thicknesses below 10 mm experienced tear-out failure. Furthermore, specimens with horizontally oriented bolt holes exhibited higher load-bearing capacity than those with vertically oriented holes. A thin flange thickness above 10 mm ensures high initial stiffness, and TF12H has a stiffness of 32.00 kN/mm. Ductility gradually reduces with the growth of thin flange thickness. Energy dissipation decreases sharply when the thin flange is thicker than 10 mm. The joint with 16 mm thick flange, 8 mm thin flange and horizontally arranged square-neck one-side bolts presents the best comprehensive performance. The proposed TS-SNUBC shows favorable bearing performance and initial stiffness, offering a promising solution for reliable and efficiently constructed connections between box columns and steel beams.

Keywords: T-stub connection; square-neck one-side bolts; tensile performance; failure mode; ultimate bearing capacity



Academic Editor: Linfeng Lu

Received: 24 May 2026

Revised: 19 June 2026

Accepted: 23 June 2026

Published: 25 June 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Prefabricated steel structures have been widely adopted in high-rise and long-span buildings due to their superior mechanical performance and high construction efficiency [1–5]. As the critical load-transferring components, beam-column joints significantly govern the bearing capacity, overall stiffness and seismic performance of the entire structure [6,7]. With the advantages of symmetric cross-section, excellent compression resistance and torsional rigidity, box columns have been extensively employed in high-rise steel

buildings [8,9]. H-shaped steel beams are commonly used in structural systems. When connected to box columns, the closed-section characteristic of box columns creates obvious construction difficulties for conventional high-strength bolted connections. This makes it challenging to develop an efficient and reliable joint connection between box columns and H-shaped steel beams.

To address the challenges of difficult and inefficient connections between closed-section steel columns and I-shaped steel beams, connection methods such as extended end-plate connection, angle steel connection, and T-shaped component connection can be adopted. However, these methods still suffer from insufficient operating space and high construction difficulty, which limits their practical application in actual engineering projects [10–12]. Researchers have adopted experimental testing, finite element (FE) simulation, and parametric analysis to optimize box column–H beam connections. FE simulation has been widely adopted to reveal the mechanical responses of structural components and connections, and it can effectively complement experimental investigations [13–15]. Gholami et al. proposed external flange plate reinforcement to eliminate the construction limitation of box column inner space [16]. Li et al. optimized joint mechanical behavior and failure mode by adjusting beam flange sizes [17]. Derakhshan and Shekastehband performed a parametric study on bolted T-stub connections, revealing the mechanical mechanism of this connection type [18]. Currently, a single-sided bolted connection is one of the important approaches to achieve stable bearing capacity and efficient construction for steel column–I-shaped steel beam joints.

Currently, single-sided bolted connection is one of the important approaches to achieve stable bearing capacity and efficient construction for steel column–I-shaped steel beam joints, and its configuration and construction method directly affect joint performance. For instance, Han and Chan [8] proposed a novel blind bolt (SCDBB) and conducted experimental and theoretical studies on its structural performance. They focused on the structural behavior of SCDBB in hollow section column connections, investigating its performance compared to existing bolts and analyzing the tensile behavior of T-stub connections under different geometric parameters. The research identified typical failure modes and corresponding design guidelines, establishing a high-precision theoretical model for connection tensile resistance. Han and co-workers [19] investigated the static performance of CFST column T-stub connections using high-strength blind bolts. They experimentally and numerically examined the group effect of blind bolts, including bolt type, anchorage length, bolt pitch/gauge distance, and the presence of infill concrete. Key parameters such as critical bolt spacing and concrete contribution were identified, and a simplified bilinear analytical model was proposed to accurately predict the connection behavior. Zhang et al. [20] explored the mechanical performance of blind-bolted T-stub connections to CFST columns through cyclic tests and numerical simulations. They compared the hysteretic behavior, failure modes and mechanical responses between blind-bolted and through-bolted joints and proposed an accurate formula for predicting connection bending resistance. Moreover, they conducted parametric analysis to quantify the effects of stiffener arrangement and flange thickness and recommended the optimal strength-matching range for T-stub flanges. Li and Zhao [21] adopted the equivalent T-stub approach recommended by Eurocode 3 and conducted experimental and theoretical studies on equivalent T-stub-to-concrete-filled stainless steel tube (CFSST) connections (T-to-CFSST) and CFSSTs themselves, using stainless steel blind bolts and normal bolts. They investigated the effects of multiple parameters on connection performance, developed and validated a finite element model, performed a parametric study, and proposed theoretical models and formulas to predict the stiffness, yield capacity, ultimate capacity and load–displacement curves of CFSSTs and T-to-CFSSTs, with good prediction accuracy. Li and Zhao [22] experimentally investigated blind-bolted

T-stub-to-stainless-steel square hollow section (SHS) connections. The study examined the effects of bolt type, bolt layout, and tube thickness on the structural behavior, failure modes, and load-carrying capacities of the connections and their individual components (bolts, T-stubs, SHSs). The authors proposed design formulas for predicting the capacities of the T-stubs and SHSs. Lee et al. [23] experimentally investigated blind-bolted T-stub connections to unfilled hollow section columns under static tension and compression. The study evaluated the flexural stiffness of the connections, classifying them as semi-rigid according to Eurocode 3. The researchers compared the experimental results with existing theoretical models for predicting column face capacity, achieving good agreement. They also developed and validated a detailed 3D FE model for the connection and performed a sensitivity analysis. Lee et al. [24] proposed and investigated a novel blind-bolted moment connection for open-section beams to unfilled hollow section columns, termed the “extended T-stub connection with back face support.” This design adds channels to a standard T-stub, connecting it to a backplate at the column’s rear face. The key innovation is that the channels distribute the beam flange tensile load to the back face, significantly reducing the demand on the flexible front column face, which typically compromises connection stiffness. Experimental and FE analysis demonstrated that this connection is significantly stiffer than a typical face-only connection and comparable to a previously tested side-plate connection. The study validated the FE model’s accuracy and concluded that the proposed connection offers a robust and reliable moment-resisting solution for low-rise construction. Therefore, the research on the tensile performance, failure mechanisms, and key influencing parameters of steel column-I-shaped steel beam joints with single-sided bolted T-shaped connections is one of the critical factors promoting the development and application of single-sided bolted connections [25,26]. To address the above issues, this paper proposes a novel T-stub connector employing square-neck single-sided bolts, as illustrated in Figure 1. A total of twelve T-stub connection specimens were designed with varying parameters, including bolt type (conventional bolt, slotted single-sided bolt, and square-neck single-sided bolt), flange thickness, and bolt hole orientation. Monotonic tensile tests were carried out to obtain the failure modes, load–displacement response, and ultimate bearing capacity of all specimens. Through comparative analysis, the mechanical response and failure mechanism of T-stub connectors under different parameter combinations were clarified. The square-neck one-side bolt adopted in the tests has been reported in previous studies and is not an original component proposed in this work. Instead, the primary innovation of the present research is the design of asymmetric T-stub connections with varied flange thicknesses. This study innovatively applies the square-neck one-side bolt to T-stub joints and conducts a series of systematic experiments for practical joints connecting box columns and H-shaped steel beams. Compared with traditional through-bolted connections, the proposed T-stub joint with square-neck one-side bolts enables bolt installation and tightening merely from the exterior side. No internal operation inside closed-box columns is needed, which significantly simplifies field assembly and enhances construction efficiency. This technology also reduces the costs caused by bolt penetration and manual work inside columns. Different from common slotted one-side bolts, the square-neck structure plays a positioning role, so no extra limiting blocks are required on site. Consequently, the proposed connection exhibits superior performance in both construction convenience and comprehensive economic benefits. Beam-column joints are critical components in modern prefabricated steel structures, which govern the overall structural stiffness, load transfer efficiency and safety margin. The research outcomes can effectively tackle the construction challenges of joints in closed steel frames, provide a reliable mechanical basis for structural optimization design, and improve the safety and constructability of prefabricated steel structures. This study also complements the theoretical research on hybrid connections

of steel structures and offers useful references for practical engineering applications and relevant design code revision.

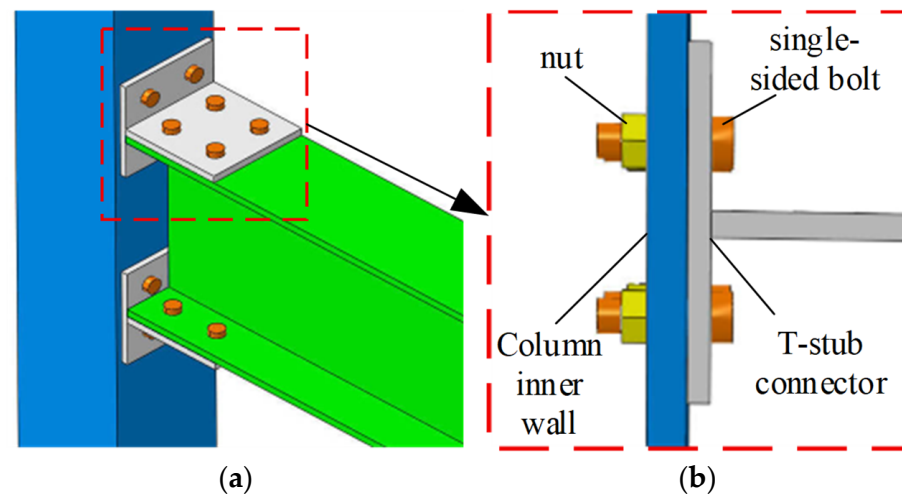


Figure 1. Connection of beam-column T-stub joints: (a) beam-column joint; (b) joint details.

2. Basic Configuration

2.1. T-Stub Slotted Single-Sided Bolted Connector

Figure 2a presents the configuration diagram of the T-stub slotted single-sided bolted connector (TS-GUBC), which consists of one thick flange plate, one thin flange plate, two web plates, and two slotted single-sided bolts. The flange plates and web plates are connected by welding, while the two flange plates are joined together using slotted single-sided bolts. Compared with conventional high-strength bolts, slotted single-sided bolts used in the T-stub connector can have their nuts directly tightened from the outer side during installation [27]. However, tightening the nuts from the outer side during the installation process may cause a certain angular deviation of the bolt head, which reduces the contact area between the bolt head and the flange plate and further impairs the joint bearing capacity. To address this issue, as shown in Figure 2b, two small iron blocks can be welded on both the left and right sides of the bolt hole on the thick flange plate in advance, thereby preventing the aforementioned problem.

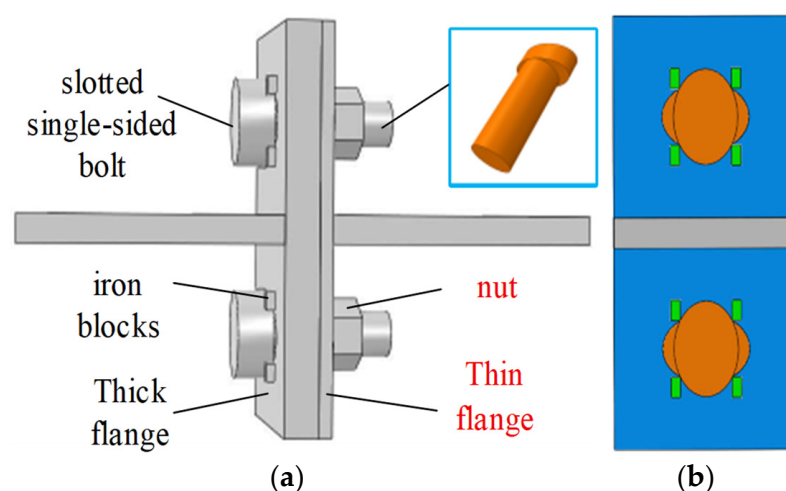


Figure 2. Configuration of T-stub slotted single-sided bolt connector: (a) T-stub slotted single-sided bolt connector; (b) welding layout of the limiting iron blocks.

2.2. T-Stub Square-Neck Single-Sided Bolt Connector

Figure 3 illustrates the structural layout of the T-stub square-neck single-sided bolt connector (TS-SNUBC). The assembly is composed of one thick flange plate, one thin flange plate, two web plates, and two square-neck single-sided bolts. The flange plates are welded to the web plates, while the two flange plates are fastened together by square-neck single-sided bolts. In addition, two bolt hole arrangements are adopted for the proposed TS-SNUBC connector, namely horizontal and vertical opening directions.

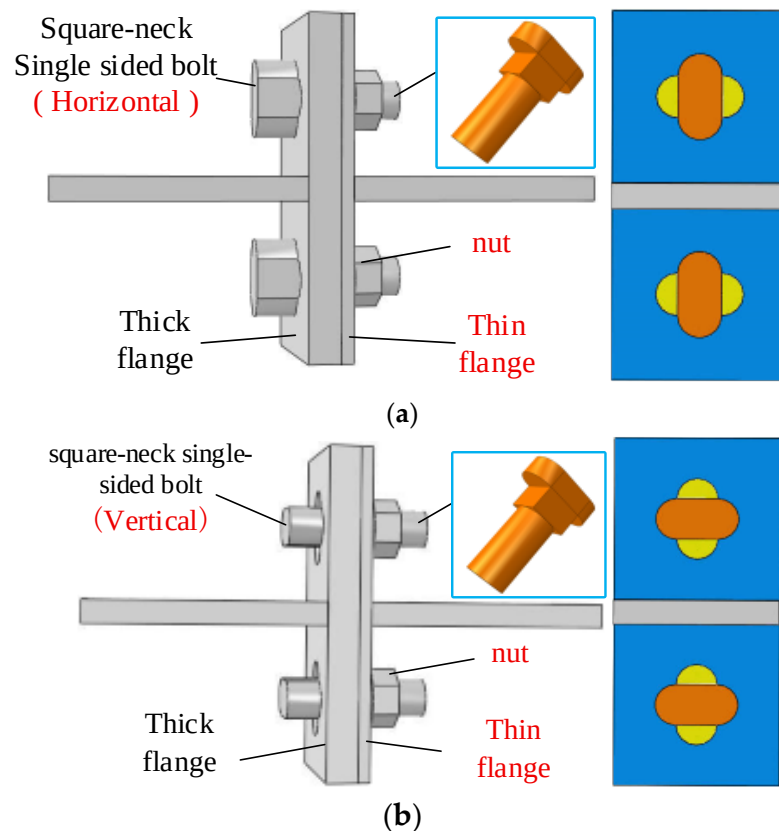


Figure 3. Configuration of T-stub square-neck single-sided bolt connector: (a) horizontal hole; (b) vertical hole.

3. Experiment Program

3.1. Specimen Design

A total of twelve T-stub specimens were designed for the experimental study, with their configurations illustrated in Figure 4. The flange length b_f was set to 172 mm, and the web length b_w was 120 mm. The thickness of the thin flange was t_{f1} , while the thickness of the thick flange t_{f2} was fixed at 16 mm, with a width b of 80 mm. Both the end distance e and d were 40 mm, and the web thickness t_w was 12 mm. Fillet welds were adopted to connect the web plates and flange plates, and G8.8-grade M20 high-strength bolts were used to fasten the T-stub connectors.

The parameters of each specimen are summarized in Table 1. Herein, “R” denotes conventional high-strength bolts, “C” represents slotted single-sided bolts, and “F” stands for square-neck single-sided bolts; “H” indicates horizontal slotted holes, and “V” denotes vertical slotted holes.

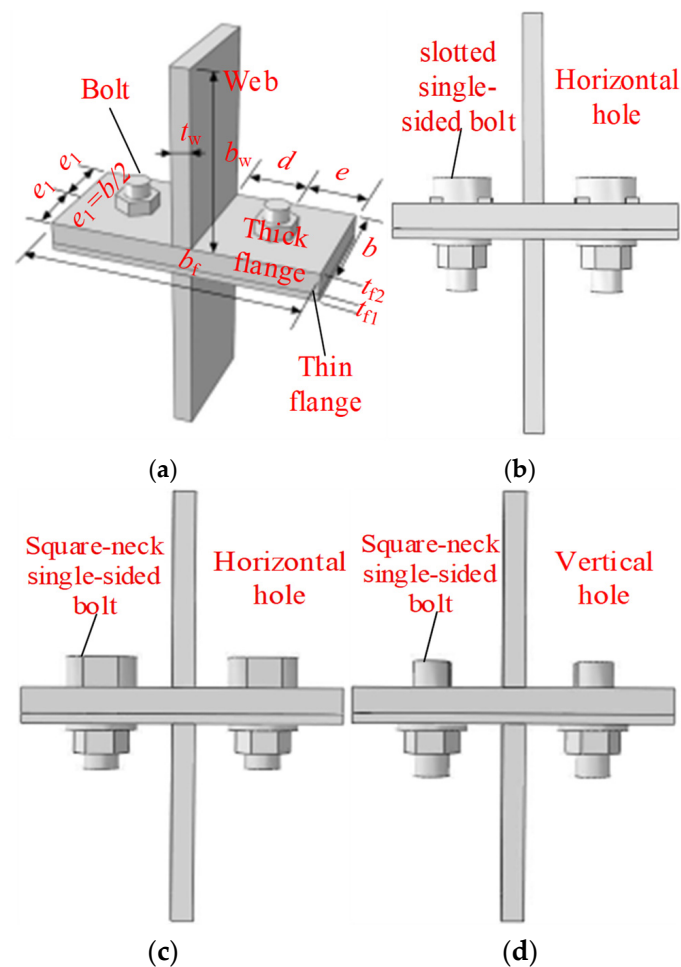


Figure 4. Components and sizes for specimens: (a) T-stub connector; (b) slotted single-sided bolt; (c) square-neck single-sided bolt (horizontal); (d) square-neck single-sided bolt (vertical).

Table 1. Specimen parameters.

Spec. Label	t_{f1}	t_{f2}	b	b_f	t_w	b_w	e	Bolt Type	Hole Direction
TR4	4	16	80	172	12	120	40	R	/
TR6	6								
TR8	8								
TC6H	6							C	Horizontal
TF6H	6								
TF8H	8								
TF10H	10								
TF12H	12								
TF6V	6							F	Vertical
TF8V	8								
TF10V	10								
TF12V	12								

3.2. Material Properties

All plates of the T-stub specimens were made of Q235 steel and fastened with 8.8-grade M20 high-strength bolts. Material property tests [28] were conducted on steel plates with different thicknesses and various high-strength bolts. The measured mechanical properties are listed in Table 2.

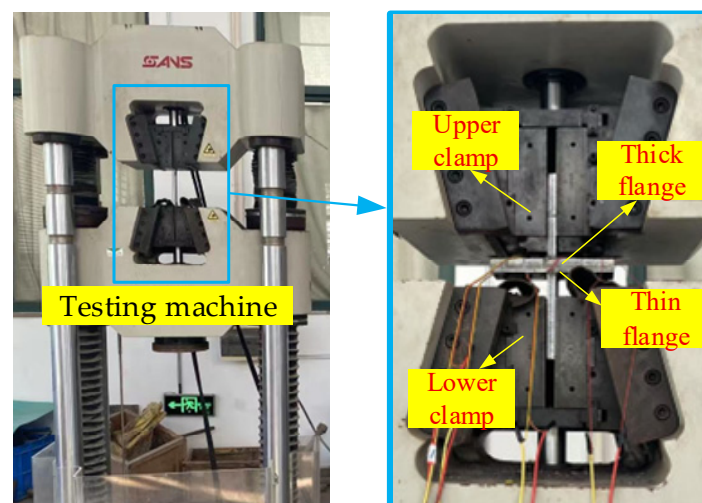
Table 2. Mechanical properties of the material.

Type	Thickness/mm	Yield Strength f_y /MPa	Ultimate Strength f_u /MPa	Elastic Modulus E /GPa	Elongation δ /%
Steel plate	4	254	352	202	25.9
	6	249	347	203	26.7
	8	244	340	205	27.1
	10	241	333	206	28.3
	12	238	326	208	27.1
	16	236	318	211	31.2
High-strength bolt	R	775	865	208	-
	C	718	807	203	-
	F	741	828	205	-

3.3. Loading Device and Loading Protocol

3.3.1. Loading Device

All tests were carried out in the structural laboratory of Nanchang University. A 200-ton electro-hydraulic servo universal testing machine was adopted to conduct monotonic tensile loading, as shown in Figure 5. Both ends of the T-stub connector were firmly clamped by the upper and lower chucks of the testing machine. The upper and lower webs of the specimen were inserted into the chuck with an embedded length of 80 mm, which ensured sufficient clamping force and effective clamping area at the specimen ends.

**Figure 5.** Loading setup.

3.3.2. Loading Protocol

Prior to formal loading, preloading was performed on all specimens. In the formal test, displacement control was adopted with a loading rate of 1 mm/min [29]. The loading was terminated when obvious failure occurred or the load dropped to 85% of the ultimate bearing capacity, at which point the specimen was regarded as reaching its limit state.

3.4. Measurement Scheme

The test measurement items mainly included displacement, applied load and strain distribution in critical regions. The displacement and load were directly acquired by the servo actuator. The layout of strain measuring points for critical regions of specimens is illustrated in Figure 6. Strain gauge L1 was arranged on the thick flange near the outer side of the web weld and the side end. Strain gauges L2 and L3 were installed on the thin

flange at positions near the free end and side end, as well as outside the web weld and at the side end. Strain gauge L4 was pasted on the lateral surface of the thin flange close to its centerline. The data sampling frequency was set to 1 Hz throughout the test.

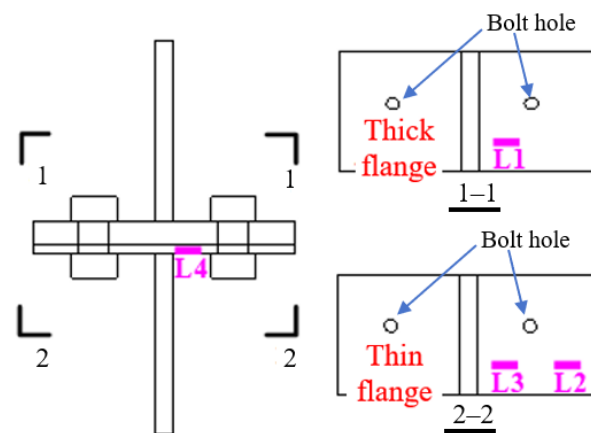


Figure 6. Layout of strain gauges.

4. Test Phenomena

4.1. Phenomena of Conventional Bolted Connection

Figure 7 compares the failure modes of specimens TR4, TR6 and TR8 with conventional bolted connections. All specimens exhibited basically identical failure processes and failure modes. At the initial loading stage, obvious opening deformation occurred in the thin flange, while no evident deformation was observed in the thick flange. With the increase in applied load, bolt extrusion on the hole wall induced local yielding of the flange material around the bolt hole. Ultimately, all specimens failed by yielding of the thin flange.

As shown in Figure 7a, specimen TR4 had a relatively thin flange thickness. Under increasing load, the thin flange continuously opened, and the bolt squeezed the hole wall, resulting in local yielding and tearing of the flange around the bolt hole. A half-opening deformation state was observed at failure. As depicted in Figure 7b, specimen TR6 shared a similar failure mode with TR4. An obvious half-opening state formed between the thin and thick flanges at the ultimate state, accompanied by remarkable bending deformation of the thin flange. As illustrated in Figure 7c, specimen TR8 adopted a thicker thin flange. Its bending deformation at failure was significantly smaller than that of TR4 and TR6. The bolt hole was widened due to extrusion and presented apparent bending, and meanwhile, cracking appeared at the weld joint between the thin flange and the web plate.

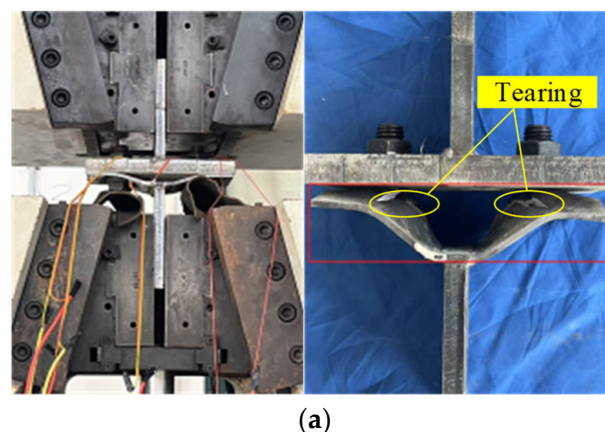


Figure 7. Cont.

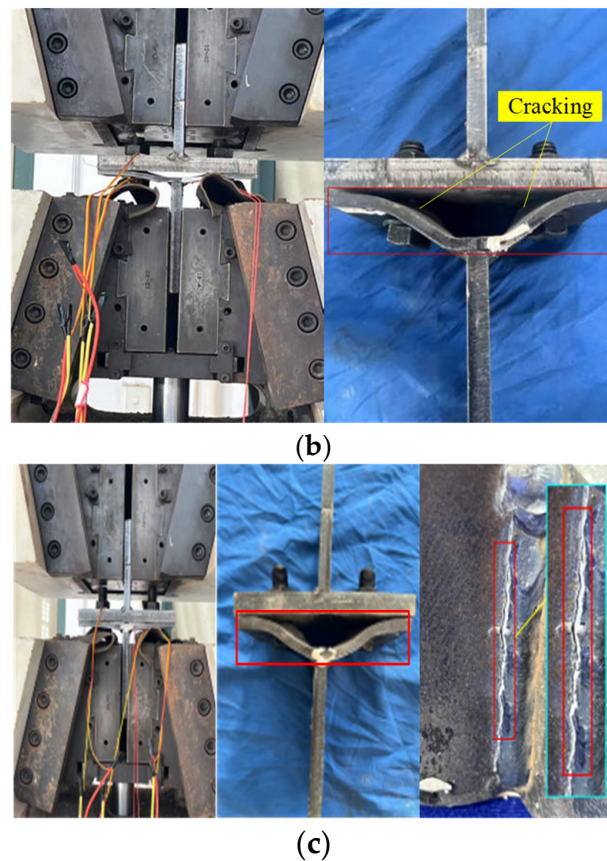


Figure 7. Failure modes of conventional bolted connection specimens: (a) specimen TR4; (b) specimen TR6; (c) specimen TR8.

4.2. Phenomena of Different Bolt Connection Types

Figure 8 shows the failure modes of specimens TC6H, TF6H and TF6V with different bolt connection types. All three specimens failed due to thin flange yielding and exhibited basically identical failure processes. During loading, the thin flange gradually opened with the increase in load, whereas no obvious deformation was observed in the thick flange. Under the ultimate load, a half-opening state was formed between the flange plates of specimens TC6H, TF6V and TF6H. In addition, obvious plastic bending deformation occurred in the thin flange plate of all specimens; the bolt holes were widened by extrusion, while the deformation of the bolts remained slight.

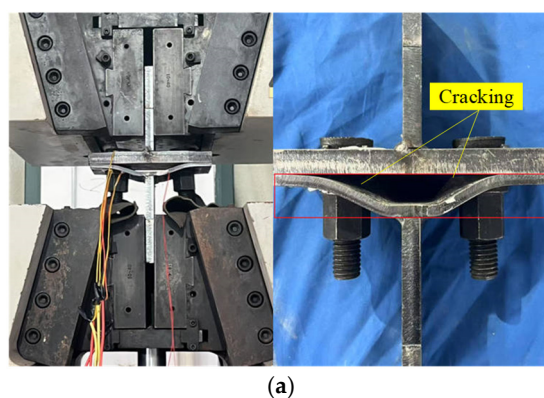


Figure 8. Cont.

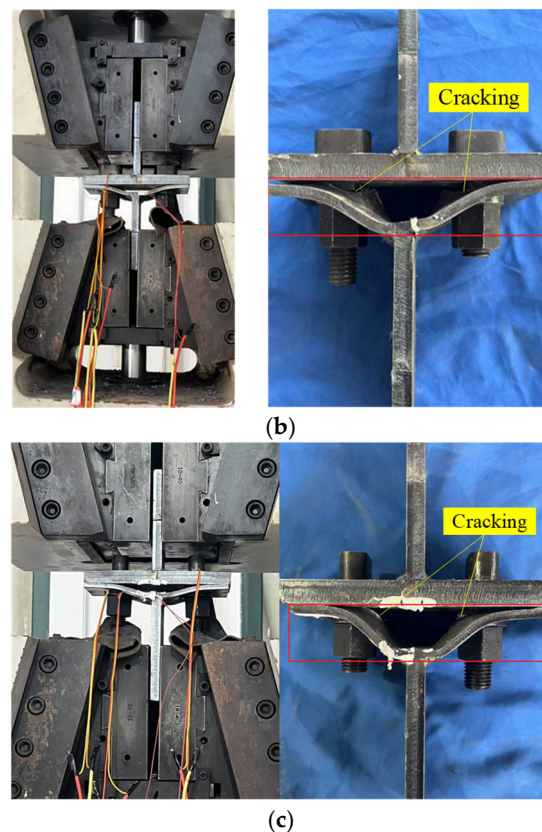


Figure 8. Failure modes of specimens with different bolt connection types: (a) specimen TC6H; (b) specimen TF6H; (c) specimen TF6V.

4.3. Phenomena of Horizontal Connection of T-Stub Square-Neck Single-Sided Bolt

Figure 9 presents the failure modes of horizontally connected specimens TF8H, TF10H and TF12H with different flange thicknesses, which are compared with specimen TF6H. As the load increased, the thin flanges gradually separated, and all specimens eventually failed by thin flange yielding under the ultimate load. By comparing Figures 8a and 9a–c, it can be seen that with the increase in thin flange thickness, the opening deformation between flanges gradually decreases. Meanwhile, the crack initiation position shifts from the outer side to the inner side of the weld between the thin flange and the web, and the bolt deformation changes from slight bending to obvious bending. For specimens TF6H and TF8H, the failure is dominated by flange deformation with minor bolt bending, and cracks occur at the outer weld toe. In contrast, specimens TF10H and TF12H have thicker flanges, which restrain flange deformation significantly but lead to remarkable bolt bending. Consequently, cracks mainly appear at the inner weld toe.

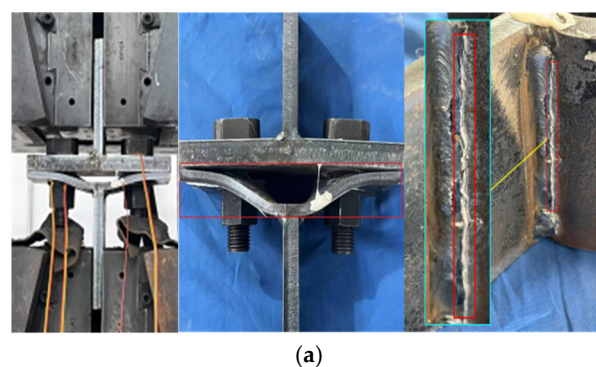


Figure 9. Cont.

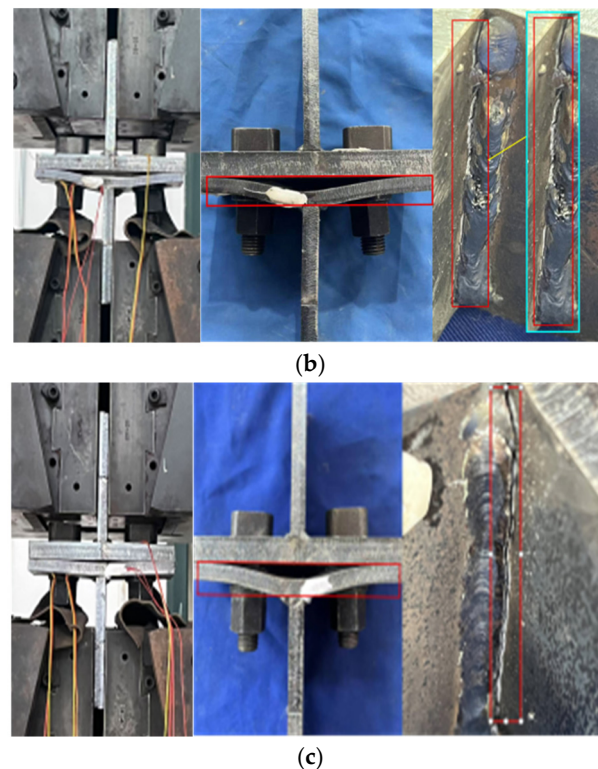


Figure 9. Failure mode of TS-SNUBC with horizontal connection: (a) specimen TF8H; (b) specimen TF10H; (c) specimen TF12H.

4.4. Phenomena of Vertical Connection of T-Stub Square-Neck Single-Sided Bolt

Figure 10 presents the failure modes of specimens TF8V, TF10V and TF12V. Under ultimate loading, all three specimens failed by yielding the thin flange, and their failure evolution was basically consistent with that of horizontally connected specimens. With the gradual increase in applied load, the deformation of the thin flange developed continuously, while no obvious deformation was observed in the thick flange. As illustrated in Figure 10a, specimen TF8V eventually exhibited a clear half-opening state. The thin flange underwent obvious plastic bending deformation, and the bolt hole suffered extrusion deformation, whereas the bolt itself showed slight distortion. As shown in Figure 10b,c, with the increase in thin flange thickness, the opening degree between the thin and thick flanges of TF10V and TF12V at the ultimate load decreased significantly. By contrast, the bending deformation of bolts became more prominent, and cracks initiated at the weld toe between the thin flange and the web plate.

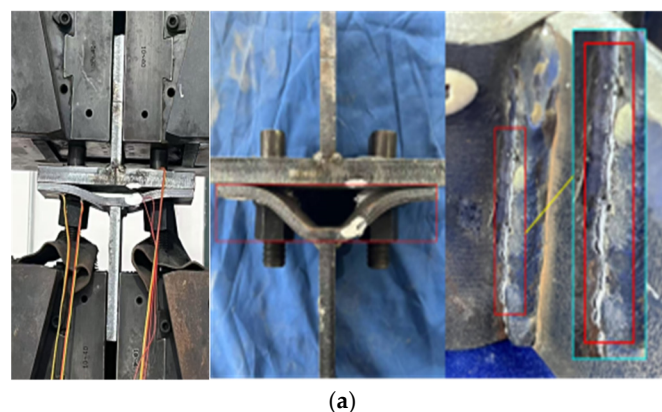


Figure 10. Cont.

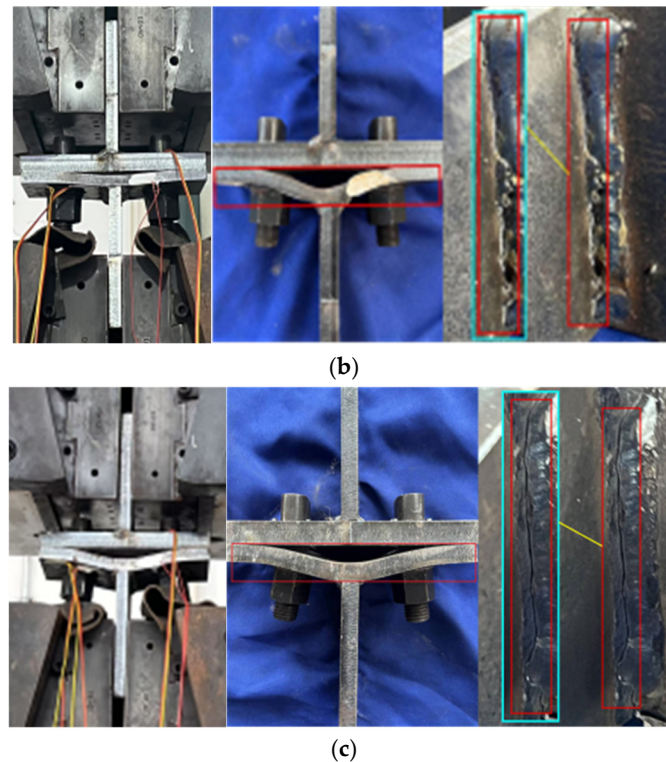


Figure 10. Failure mode of TS-SNUBC specimens with vertical connection: (a) specimen TF8V; (b) specimen TF10V; (c) specimen TF12V.

Combined with the deformation characteristics during loading and final failure, the load transfer path of the T-stub joint can be summarized as follows: external loads are transmitted from the H-shaped steel beam to the T-stub web and then distributed to thick and thin flanges. The one-side bolts undertake the tension and shear force between the two flanges. For specimens with thin flanges, stress and load tend to concentrate around bolt holes; with the increase in flange thickness, the load is gradually transferred to the bolt shank. Different bolt types and hole layouts lead to distinct bolt hole interaction behaviors. Slotted one-side bolts are susceptible to deflection of the bolt head, which causes local concentrated bearing on the hole wall. Benefiting from the limiting effect of the square neck, square-neck bolts maintain uniform circumferential bearing contact. Moreover, compared with vertically arranged holes, horizontally arranged bolt holes can mitigate local stress concentration on hole walls. Typical failure modes such as hole bearing enlargement, bolt bending and flange tearing further verify the above mechanical behaviors.

5. Load–Displacement Response

5.1. Response of Conventional Bolted Connections

Figure 11 compares the load–displacement curves of specimens with conventional bolted connections. At the initial loading stage, both the initial stiffness and the displacement corresponding to the yield load increase with the growth of thin flange thickness. The ultimate loads of specimens TR4, TR6 and TR8 are 88.13 kN, 107.96 kN and 140.17 kN, respectively, while their ultimate displacements are 35.71 mm, 27.14 mm and 24.44 mm. Compared with specimen TR4, which has a thin flange thickness of 4 mm, the bearing capacities of TR6 and TR8 increase by 22.50% and 59.05%, respectively. This indicates that for T-shaped joints with conventional bolts, the ultimate bearing capacity rises steadily as the thin flange thickness increases.

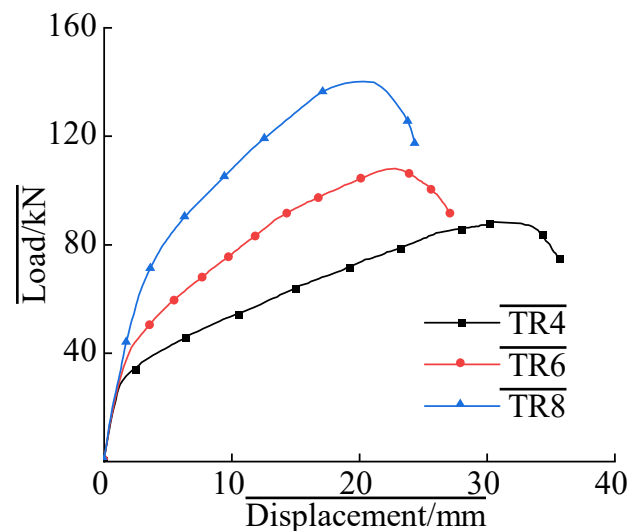


Figure 11. Load–displacement curves of conventional bolted connection specimens.

5.2. Response of Different Bolt Connection Types

Figure 12 compares the load–displacement curves of specimens with different bolt connection forms. At the initial loading stage, the initial stiffness decreases gradually in the order of conventional bolts, square-neck single-sided bolts, and channel-type single-sided bolts. The ultimate loads of specimens TR6, TC6H, TF6H and TF6V are 107.96 kN, 76.26 kN, 98.09 kN and 92.97 kN, respectively. Compared with the conventional bolt connection, their bearing capacities are reduced by 29.36%, 9.14% and 14.26%, respectively. Their corresponding ultimate displacements are 27.22 mm, 21.27 mm, 27.66 mm and 28.87 mm. It can be concluded that under the same flange thickness, the conventional bolted connection achieves the highest ultimate bearing capacity. The horizontal and vertical arrangements of square-neck single-sided bolts exhibit similar ultimate strength and deformation performance. In contrast, the channel-type single-sided bolt shows the lowest bearing capacity and deformability, which is not recommended for practical engineering design.

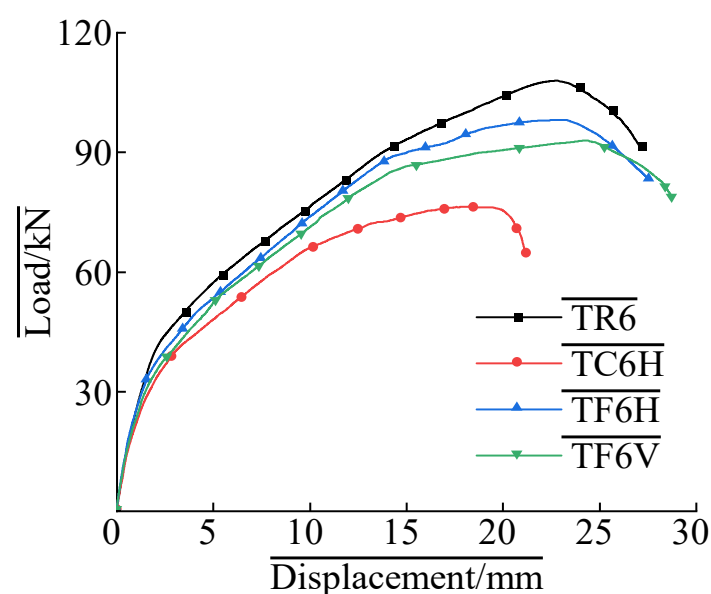


Figure 12. Load–displacement curves of specimens with different bolted connection forms.

5.3. Response of Horizontal Connection of T-Shaped Square-Neck Single-Sided Bolts

Figure 13 compares the load–displacement curves of specimens with horizontally arranged T-shaped square-neck single-sided bolt connections. The ultimate loads of specimens TF6H, TF8H, TF10H, TF12H, TR6 and TR8 are 98.09 kN, 135.81 kN, 152.62 kN, 169.02 kN, 107.96 kN and 140.17 kN, respectively, while their corresponding ultimate displacements are 27.66 mm, 25.11 mm, 12.22 mm, 10.94 mm, 27.22 mm and 24.44 mm. It can be seen that for horizontal connections adopting T-shaped square-neck single-sided bolts, increasing the thin flange thickness can remarkably enhance the ultimate bearing capacity of T-shaped joints. When the thin flange thickness reaches no less than 10 mm, the connection presents higher stiffness but lower deformation capacity. Furthermore, a comparative analysis between TF6H and TR6, and TF8H and TR8 in terms of bearing capacity and deformation performance shows that the ultimate bearing capacity of conventional bolted specimens is merely 10.62% and 3.21% higher than that of horizontally connected square-neck bolt specimens. The difference in load-bearing performance between the two connection methods is relatively slight.

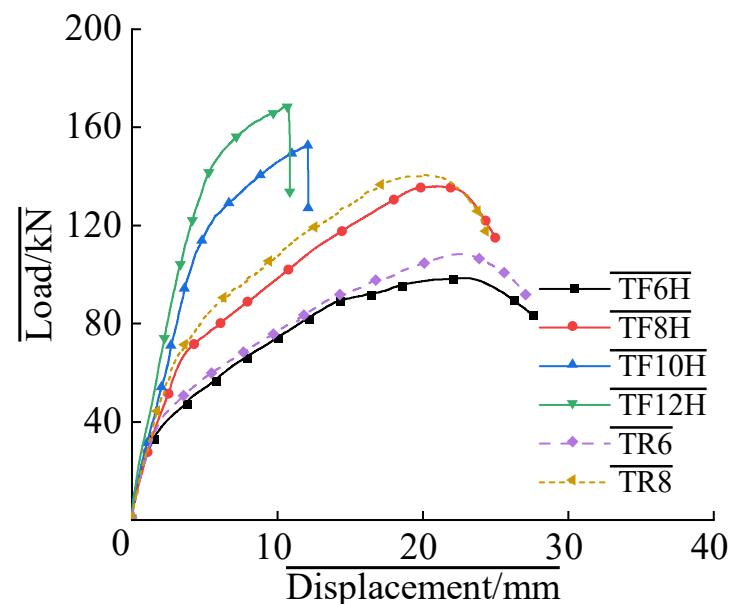


Figure 13. Load–displacement curves of TS-SNUBC with horizontal connection.

5.4. Response of Vertical Connection of T-Shaped Square-Neck Single-Sided Bolts

Figure 14 compares the load–displacement curves of specimens with vertically arranged T-shaped square-neck single-sided bolt connections. The ultimate loads of specimens TF6V, TF8V, TF10V, TF12V, TR6 and TR8 are 92.97 kN, 129.74 kN, 145.98 kN, 164.91 kN, 107.96 kN and 140.17 kN, respectively, and their corresponding ultimate displacements are 28.87 mm, 26.04 mm, 13.74 mm, 12.11 mm, 27.22 mm and 24.44 mm. For vertical connections using T-shaped square-neck single-sided bolts, increasing the thin flange thickness can also effectively improve the bearing capacity of the connection. When the thin flange thickness is no less than 10 mm, the stiffness and bearing capacity are obviously superior to those of specimens with thicknesses of 6 mm and 8 mm. Moreover, by comparing TF6V with TR6 and TF8V with TR8, the ultimate bearing capacities of conventional bolted specimens are 16.12% and 8.04% higher than those of vertically connected square-neck bolt specimens. The capacity discrepancy is much more significant than that of horizontal single-sided bolt connections. Accordingly, the horizontal connection form is recommended in practical engineering design.

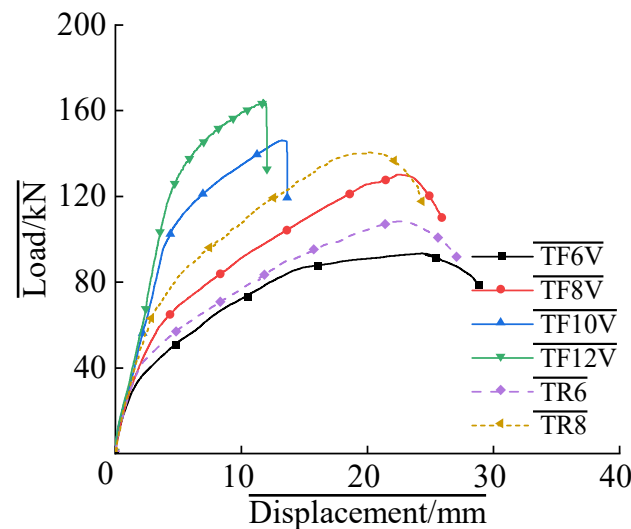


Figure 14. Load–displacement curves of TS-SNUBC with vertical connection.

5.5. Analysis and Discussion

The evolution of load–displacement curves also reflects the above load transfer rules and bolt hole interaction. The variation in flange thickness changes the load distribution pattern, while bolt type and hole arrangement directly affect the contact state and bearing performance between bolts and hole walls throughout the loading process.

Based on the load–displacement curves of all specimens, the corresponding ultimate loads and ultimate displacements, and key quantitative mechanical indicators (initial stiffness, ductility index and cumulative energy dissipation) were obtained, as presented in Table 3. The determination methods of key quantitative mechanical indicators [30,31] are shown in Figure 15, and the key quantitative mechanical indicators of all specimens are compared in Figure 16. Among the influencing factors, flange thickness and bolt type are the two primary parameters affecting the mechanical properties of T-shaped connectors. When the bolt type remains consistent, the ultimate bearing capacity of T-shaped connectors increases significantly with the increase in thin flange thickness. When the thin flange thickness is no less than 10 mm, both the bearing capacity and initial stiffness of the connection are relatively high. For specimens with the same thin flange thickness, the initial stiffness and bearing capacity decrease sequentially in the order of conventional bolts, square-neck single-sided bolts, and channel-type single-sided bolts. However, the minimum difference in ultimate bearing capacity between horizontally connected square-neck single-sided bolts and conventional bolts is only 3.21%, indicating no significant discrepancy. Therefore, the adoption of T-shaped connectors with a thin flange thickness of no less than 10 mm and horizontally arranged square-neck single-sided bolts can ensure the bearing capacity of the connectors and the box-section steel column-beam joints, while improving the construction efficiency of the joints. The special bolts used in the tests are custom products without public manufacturing details. Despite the lower material strength compared with conventional high-strength bolts, they achieve good overall performance owing to direct load transfer, high stiffness, reliable anti-rotation, solid T-head anchorage and reduced prying force. Their comprehensive performance matches that of ordinary high-strength bolts.

Shear deformation greatly affects the performance of composite members with steel cores. Szymczak-Graczyk et al. [32] presented a shear correction factor for non-homogeneous sections, whose theory supports the analysis of composite steel connections and the results in this study. Apart from ultimate load and qualitative failure observa-

tions, key quantitative mechanical indicators, including initial stiffness, ductility index and cumulative energy dissipation, are further analyzed as follows.

Table 3. Summary of the results of specimens.

Spec. Label	P_p /kN	Δ_u /mm	μ	K /(kN/mm)	E_{sum} /(kN·mm)	$P_p/P_{p,TR6}$
TR4	88.13	35.71	2.13	24.31	2193.62	0.82
TR6	107.96	27.14	2.04	24.5	2320.7	1.00
TR8	140.17	24.44	1.94	25.42	2600.41	1.30
TC6H	76.26	21.27	2.46	21.45	1268.82	0.71
TF6H	98.09	27.66	2.31	23.33	2100.52	0.91
TF8H	135.81	25.11	1.96	24.3	2516.81	1.26
TF10H	152.62	12.22	1.69	26.88	1312.16	1.41
TF12H	169.02	10.94	1.75	32	1319.48	1.57
TF6V	92.97	28.87	2.34	22.37	2114.83	0.86
TF8V	129.74	26.04	1.96	23.75	2451.18	1.20
TF10V	145.98	13.74	1.8	25.51	1447.06	1.35
TF12V	164.91	12.11	1.74	29.83	1422.57	1.53

Note: P_p is the ultimate load corresponding to the peak point, Δ_u is the ultimate displacement corresponding to the failure point, and $P_p/P_{p,TR6}$ is defined as the ratio of the ultimate load of each specimen to that of specimen TR6. The ductility index μ is defined as the ratio of Δ_u to Δ_y , as illustrated in Figure 15.

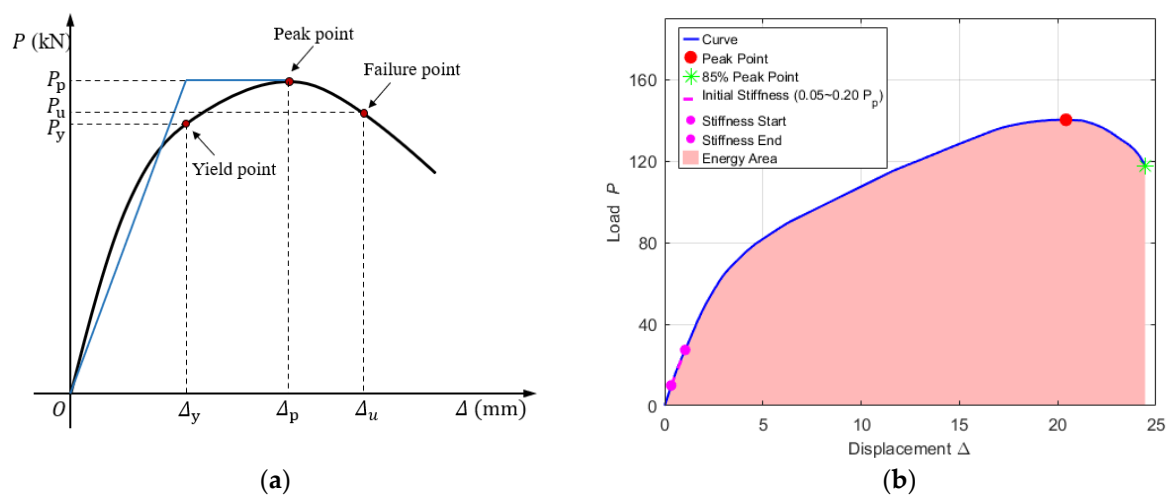


Figure 15. Determination methods of key quantitative mechanical indicators: (a) determination methods of characteristic points; (b) determination methods of initial stiffness and cumulative energy dissipation.

Initial stiffness is adopted to evaluate the ability of connections to resist elastic deformation. For specimens with the same bolt type, increasing the thickness of the thin flange can effectively enhance the initial stiffness. When the thickness of the thin flange is no less than 10 mm, the specimens maintain a relatively high initial stiffness and exhibit excellent elastic rigidity. At the same thin flange thickness, the initial stiffness of connections follows the descending order: conventional high-strength bolts, square-neck one-side bolts and slotted one-side bolts. For joints with square-neck one-side bolts, specimens with horizontally arranged bolt holes have higher initial stiffness than those with vertically arranged holes. Particularly, specimen TF12H achieves an initial stiffness of 32.00 kN/mm, presenting outstanding rigidity performance. The ductility index reflects the plastic deformation capacity of T-stub joints. Specimens assembled with slotted one-side bolts show the best ductility, while joints using square-neck one-side bolts and conventional high-strength bolts possess moderate ductility. For connections with square-neck one-side bolts, ductility gradually decreases as the thin flange thickness increases. A thicker thin flange restrains the develop-

ment of plastic deformation in the flange and reduces the overall deformation capacity of the joint. With identical flange dimensions, specimens with vertically arranged bolt holes exhibit slightly better ductility than those with horizontally arranged holes. Cumulative energy dissipation characterizes the energy absorption behavior of connections under tensile loading. Increasing the thin flange thickness can effectively improve the cumulative energy dissipation of specimens. Among all bolt types, conventional bolted connections deliver the optimal energy dissipation capacity, and square-neck one-side bolt connections show a comparable performance, whereas slotted one-side bolt connections have the lowest energy dissipation capacity. When the thin flange thickness of square-neck one-side bolt connections exceeds 10 mm, the ultimate displacement of the joint decreases remarkably, resulting in an obvious decline in the overall energy dissipation capacity. According to the above quantitative performance indicators, the T-stub connection with a 16 mm thick flange, an 8 mm thin flange and horizontally arranged square-neck one-side bolts is recommended. This joint possesses high ultimate bearing capacity, excellent initial stiffness, favorable deformation performance and reliable energy dissipation capacity. It fully meets the service requirements of box-column-to-steel-beam joints in practical engineering, while retaining the prominent advantage of convenient on-site installation of one-side bolts.

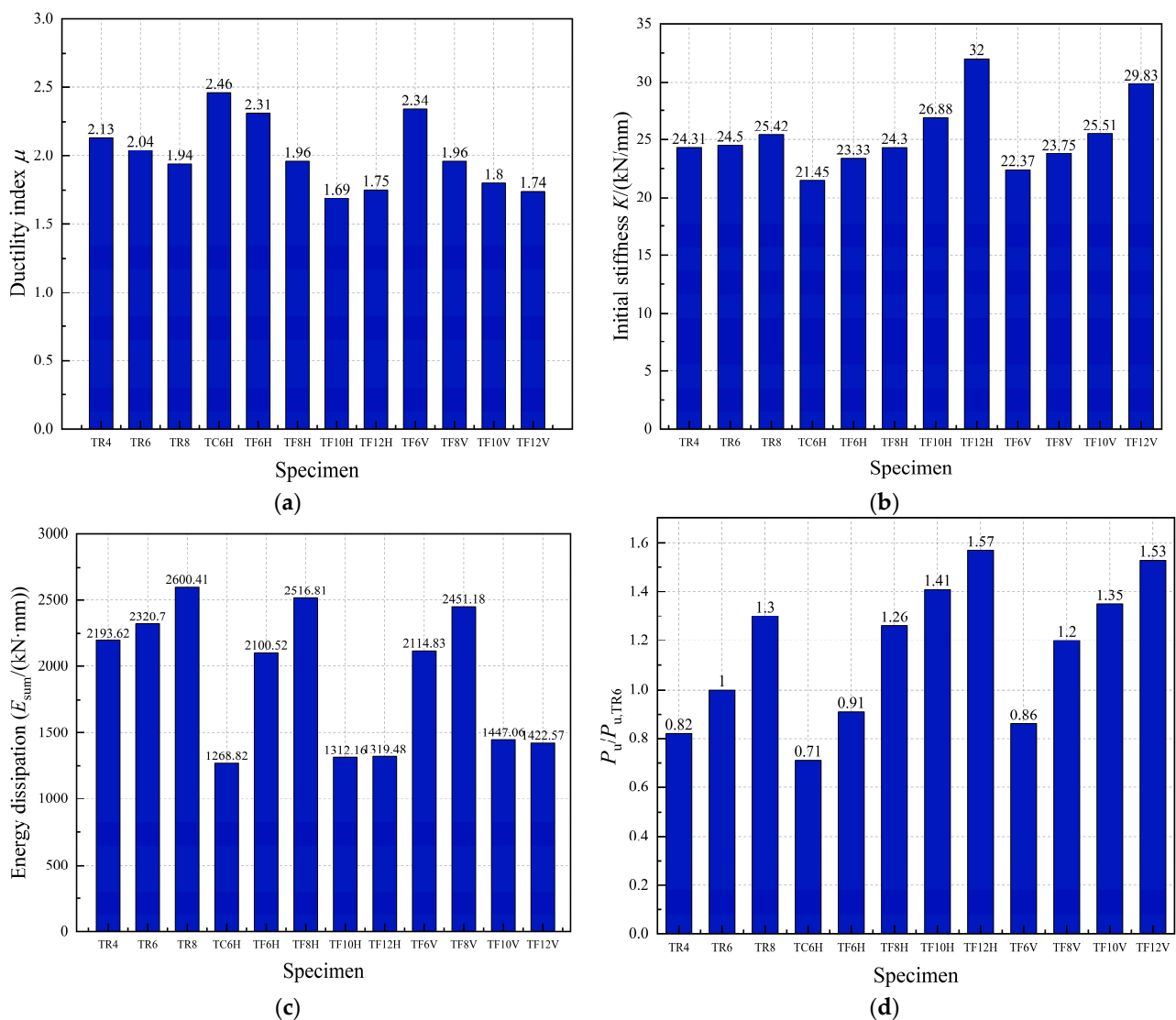


Figure 16. Key quantitative mechanical indicators of specimens: (a) ductility index; (b) initial stiffness; (c) cumulative energy dissipation; (d) $P_u/P_{u,TR6}$.

A total of 12 specimens were tested in this investigation, and each specimen was designed for a unique working condition. Accordingly, no parallel repeated specimens were arranged, and standard repeatability verification for identical samples was not performed. All specimens were manufactured, installed and tested in accordance with the same criteria and loading procedures. The experimental operations were standardized to ensure the reliability of all test data. The proposed connection has a simple configuration and facilitates on-site installation. Its material, fabrication and construction costs are roughly the same as those of traditional high-strength bolted connections. In engineering practice, this solution greatly improves the assembly efficiency of joints connecting closed box columns and steel beams in prefabricated steel structures, while keeping the total cost and structural safety at a reasonable level.

Although this study has revealed the tensile performance of T-stub joints with square-neck one-side bolts, several limitations exist and will affect the popularization and application of the research results. Firstly, only monotonic axial tensile tests were conducted, and cyclic loading was not taken into account. Therefore, the seismic behavior, fatigue resistance and mechanical responses under complex loading conditions cannot be characterized, restricting the application of the findings in the seismic design of steel structures. Secondly, the experimental variables are confined to bolt type, thin flange thickness and bolt hole orientation. Other influential parameters, including bolt pretension, bolt spacing, edge distance and steel grade, were not explored. Since these factors also greatly affect the performance of bolted connections, the design recommendations proposed herein are only applicable to the parameter range of this test and cannot be directly applied to members with different dimensions or material grades. Thirdly, the analysis is performed based on macroscopic test observations and load–displacement curves. Due to the absence of refined finite element simulation and theoretical formula derivation, the analysis of stress concentration near bolt holes, bolt deformation and internal load transfer mechanisms is relatively shallow, and it is impossible to establish a general theoretical calculation formula for such joints based on current results.

6. Conclusions

This paper proposes a T-shaped single-sided bolted connection based on square-neck bolts and conducts uniaxial tensile tests to explore its mechanical properties. The main conclusions are as follows:

- (1) The failure process of each test specimen is mainly characterized by obvious opening deformation of the thin flange, and the bolt hole wall is squeezed, leading to yielding of the flange material around the hole. During the failure process, there is no obvious deformation of the thick flange, but a “semi-open” state is formed between the thin and thick flanges.
- (2) The ultimate bearing capacity of the square-neck single-sided bolt connection is only 3.21% lower than that of the conventional bolt connection at minimum, showing a small difference in load-bearing performance. In contrast, the channel-type single-sided bolt connection has a 29.36% lower ultimate bearing capacity compared with the conventional bolt connection, so it is not recommended for engineering applications.
- (3) With the increase in the thickness of the thin flange, the ultimate bearing capacity and initial stiffness of the T-shaped connector increase significantly. Increasing the flange thickness can effectively improve the stiffness and load-bearing performance of the connection.
- (4) Thin flange thickness, bolt type and bolt hole orientation have obvious quantitative effects on joint performance. A thin flange thickness of 10 mm and above maintains high initial stiffness, and TF12H has a stiffness of 32.00 kN/mm. Ductility reduces

with increasing thin flange thickness, while slotted one-side bolt joints exhibit the greatest plastic deformation capacity. Energy dissipation is weakened significantly when the thin flange thickness is over 10 mm. The T-stub connection with a 16 mm thick flange, 8 mm thin flange and horizontally arranged square-neck one-side bolts is determined as the optimal scheme for engineering application.

- (5) The T-shaped connector based on square-neck single-sided bolts proposed in this paper has excellent bearing capacity and initial stiffness, which can form a reliable connection between box columns and steel beams. It not only ensures structural safety but also effectively improves construction efficiency, which is suitable for popularization and application in practical engineering.

This study generates valuable experimental data and summarizes the mechanical behavior rules that can benefit future related research. The conclusions are expected to provide references for the improvement of steel structure design specifications and promote the field application of one-side bolt connections. This paper presents only experimental results of the tested joints. Further research will include theoretical formula derivation and finite element analysis. These supplementary studies will be completed and published independently in the future to complement the current experimental data.

Author Contributions: Conceptualization, T.Q. and S.H.; methodology, Y.Z. and S.H.; software, T.Q. and H.C.; validation, Y.Z., T.Q. and Y.L.; formal analysis, Y.Z. and T.Q.; investigation, T.Q. and S.H.; resources, Y.Z. and S.H.; data curation, T.Q. and Y.L.; writing—original draft preparation, T.Q. and H.C.; writing—review and editing, Y.Z., H.C. and S.H.; visualization, T.Q. and Y.L.; project administration, Y.Z., H.C. and S.H.; funding acquisition, S.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (No. 52468025) and the Young Leader of Science and Technology Research Project for Jiangxi Province (No. 20232BCJ23065).

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

TS-SNUBC T-stub connection with square-neck one-side bolts

References

1. Liu, S.W.; Chen, O.W.; Liao, Y.; Zeng, S.Z.; Hu, S.J. Prediction of the overstrength for ordinary shear links in eccentrically braced frames. *Structures* **2026**, *84*, 110958. [[CrossRef](#)]
2. Hu, S.J.; Liu, S.W.; Zeng, S.Z.; Zhang, B.; Xu, Z.X. Investigating seismic performance of a novel self-centering shear link in EBF utilizing experimental and numerical simulation. *J. Constr. Steel Res.* **2025**, *224*, 109129. [[CrossRef](#)]
3. Liu, S.W.; Chen, S.Y.; Zeng, S.Z.; Zhang, B.; Hu, S.J. Seismic performance analysis of K-shaped EBF with an innovative crack-resistant composition beam. *J. Build. Eng.* **2025**, *101*, 111818. [[CrossRef](#)]
4. Che, J.; Chen, M.; Zhang, T.; Sun, Y. Experimental and numerical investigation on the effect of shear spans and axial loads for the seismic performance of drift-hardening concrete walls. *J. Build. Eng.* **2026**, *120*, 115485. [[CrossRef](#)]
5. Xiao, Y.; Li, L.; Wang, H. Effects of wind field non-uniformity and non-stationarity on suspender fatigue damage in long-span steel truss suspension bridges. *Eng. Struct.* **2026**, *358*, 122610. [[CrossRef](#)]
6. Hu, S.J.; Xu, H.W.; Zeng, S.Z.; Chen, T.; He, K. Experimental study on seismic performance of precast high-strength RC beam-column joint with embedded channel steel and UHPC. *Structures* **2025**, *81*, 110235. [[CrossRef](#)]
7. Cai, H.L.; Wang, W.; Gao, B.Y.; Yuan, Z.W.; Qian, Y.M.; Shi, X.X. Seismic shear behavior of partially-encased composite column to steel beam joint: Experiment. *J. Constr. Steel Res.* **2024**, *222*, 108997. [[CrossRef](#)]

8. Han, X.Z.; Chan, T.M. Tensile behaviour of swift-constructed demountable blind bolted T-stub to hollow section column connection. *Eng. Struct.* **2025**, *336*, 120086. [[CrossRef](#)]
9. Yang, Z.J.; Sun, L.S.; Liu, M. Axial compressive behavior of high-strength spiral-confined high-strength concrete-filled high-strength square steel-tube columns. *J. Constr. Steel Res.* **2025**, *226*, 109285. [[CrossRef](#)]
10. Mohseni, M.; Ghassemieh, M.; Mirghaderi, R. I-beam to concrete-filled SHS column using external diaphragm-side plate connections. *J. Constr. Steel Res.* **2025**, *234*, 109706. [[CrossRef](#)]
11. Yu, J.; Li, Y.; Wang, Y.H. Seismic performance of beam-end combination node with replaceable angle unilateral connection. *J. Build. Struct.* **2024**, *45*, 32–39. (In Chinese)
12. Jiang, L.Q.; Yang, H.L.; Nie, J.W. Tensile Performance of T-Stub Components with T-Head One-Side Bolts. *Prog. Steel Build. Struct.* **2025**, *27*, 77–87. (In Chinese)
13. Staszak, N.; Garbowski, T.; Szymczak-Graczyk, A. Solid Truss to Shell Numerical Homogenization of Prefabricated Composite Slabs. *Materials* **2021**, *14*, 4120. [[CrossRef](#)] [[PubMed](#)]
14. Staszak, N.; Szymczak-Graczyk, A.; Garbowski, T. Elastic Analysis of Three-Layer Concrete Slab Based on Numerical Homogenization with an Analytical Shear Correction Factor. *Appl. Sci.* **2022**, *12*, 9918. [[CrossRef](#)]
15. Kopras, M.; Buczkowski, W.; Szymczak-Graczyk, A.; Walczak, Z.; Gogolik, S. Experimental Validation of Deflections of Temporary Excavation Support Plates with the Use of 3D Modelling. *Materials* **2022**, *15*, 4856. [[CrossRef](#)] [[PubMed](#)]
16. Gholami, M.; Deylami, A.; Tehranizadeh, M. Seismic performance of flange plate connections between steel beams and box columns. *J. Constr. Steel Res.* **2013**, *84*, 126–136. [[CrossRef](#)]
17. Li, Y.; Zhang, Z.W.; Liu, H.; Wang, J. Analysis of Factors Affecting the Seismic Performance of Widened Flange Connections in Mid-Flange H-Beams and Box Columns. *Buildings* **2024**, *14*, 3170. [[CrossRef](#)]
18. Derakhshan, H.; Shekastehband, B. Seismic Performance of Bolted T-Stub Beam-to-Box Column Connection. *Structures* **2023**, *56*, 104873. [[CrossRef](#)]
19. Debnath, P.P.; Ning, W.J.; Chan, T.M. Experimental, numerical, and analytical assessment for static performance of concrete-filled steel tube T-stub connections with group of high-strength blind-bolts. *Eng. Struct.* **2025**, *338*, 120586. [[CrossRef](#)]
20. Zhang, Y.F.; Zhang, J.H.; Demoha, K. Further analysis on mechanical behaviors of blind-bolted T-stub connections to CFDST columns. *Structures* **2023**, *48*, 1964–1976. [[CrossRef](#)]
21. Li, Y.L.; Zhao, X.L. Study on stainless steel blind bolted T-stub to concrete-filled stainless steel tube connections. *Eng. Struct.* **2022**, *257*, 114107. [[CrossRef](#)]
22. Li, Y.L.; Zhao, X.L. Experimental study on stainless steel blind bolted T-stub to square hollow section connections. *Thin-Walled Struct.* **2021**, *167*, 108259. [[CrossRef](#)]
23. Lee, J.; Goldsworthy, H.M.; Gad, E.F. Blind bolted T-stub connections to unfilled hollow section columns in low rise structures. *J. Constr. Steel Res.* **2010**, *66*, 981–992. [[CrossRef](#)]
24. Lee, J.; Goldsworthy, H.M.; Gad, E.F. Blind bolted moment connection to unfilled hollow section columns using extended T-stub with back face support. *Eng. Struct.* **2011**, *33*, 1710–1722. [[CrossRef](#)]
25. Liu, Y.; Chen, J.; Zhang, X.; Tan, D. Fatigue behaviour of blind bolts under tensile cyclic loads. *J. Constr. Steel Res.* **2018**, *148*, 16–27. [[CrossRef](#)]
26. Tahir, M.M.; Mohammadhosseini, H.; Ngian, S.P.; Effendi, M.K. I-beam to square hollow column blind bolted moment connection: Experimental and numerical study. *J. Constr. Steel Res.* **2018**, *148*, 383–398. [[CrossRef](#)]
27. Liang, G.; Guo, H.C.; Liu, Y.H.; Li, Y. Finite element analysis of mechanical property of Q690 high strength steel T-stub joints. *Earthq. Eng. Vib.* **2017**, *37*, 90–97. (In Chinese) [[CrossRef](#)]
28. GB/T228, 1-2010; Metallic Materials-Tensile Testing-Part 1: Method of Test at Room Temperature. Standards Press of China: Beijing, China, 2010. (In Chinese)
29. Lin, T.; Wang, Z.; Hu, F.X.; Hou, W. Comparison in tensile behaviour of conventional and high-strength steel welded-plate pre-loaded T-stubs. *Structures* **2022**, *43*, 93–104. [[CrossRef](#)]
30. Wang, W.; Cai, H.L.; Bai, C.Y.; Bao, H.Y.; Gao, B.; Yuan, Z.; Wang, K. Seismic performance of partially encased concrete composite columns with corrugated web. *J. Build. Eng.* **2023**, *77*, 107481. [[CrossRef](#)]
31. Cai, H.L.; Wang, W.; Yao, X.Y.; Hu, S.J. Numerical Simulation of Partially-Encased Composite Columns Under Monotonic and Cyclic Loading. *Int. J. Steel Struct.* **2026**, *26*, 255–266. [[CrossRef](#)]
32. Szymczak-Graczyk, A.; Guri, Z.; Canaj, I.; Garbowski, T. Generalized Shear Correction Factor for Non-Homogeneous Beam Cross-Sections with an Embedded Steel Core. *Struct. Durab. Health Monit.* **2026**, preprint. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.