

Experimental Study on Truss-Column Pinned Connections in Large-Span Steel Structures

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Abstract. A pin-connected joint, which was intended to accommodate a certain in-plane rotation and resist the shear forces, was introduced in this paper. Pinned-connections were applied on Truss-Column joints to support the heavy-loaded floors and roofs in a long-span steel structure. The Pinned-connection was designed in accordance with European code, and compared with other standards such as America standard and Australia standard. To better understand the behavior of materials and structure of this pin-connection structural system, four specimens, including two full-scale pin-connections and two truss connections, were tested to investigate the performance under both monotonic and cyclic loads. The load–displacement curves, hysteretic curve and ultimate loads were obtained, and the failure mode, capacity and ductility were discussed. The experimental and numerical results indicated that the pin-connection behaved good ductility, load transfer ability and capacity.

Introduction

The pin-connected joints have been widely used in bridges and mechanical engineering. Pin-connection transfers vertical and horizontal shear loads and cannot resist any bending or moment forces, so it is often regarded as a complete hinge joint in structural designs. In recent years, pinned connections have been adopted in building structures such as supports, beam-to-column joints and bracing system [1]. Li Jiawu [2] provided a systematic study on the design of pin connections and discussed the design details. With the rapid development of contact problem analysis methods and calculation software, the application of numerical solution methods such as finite element method in these types of connections have made significant progress [3]. Some scholars [4] implemented finite element software Ansys to establish a full-size model of the typical pin connection of the building structure to study the contact force distribution, and conducted a theoretical analysis of several major factors affecting the pin contact force distribution.

The experimental study on pin-connection, which has been carried out over decades, has generally been relatively limited in mechanical area. David Duerr [5] built a comprehensive test program to investigate the behaviour of pin plates under static loading and proposed a set of solutions for calculating the strength. Dayi Ding [6] applied pin connections for truss-column in a commercial steel structure, and studied the material performance of the pin shafts and ear plates as well as full-scale experimental test under static loading and cyclic loading; Jianwei Ma [7] analyzed pin-connected joints for truss-columns connections of large-span steel structures to support heavy-loaded floor by finite element method, and carried out experimental research on pin-connections.

In this paper, a novel pin-connection joint was proposed for truss-column connection to support floor system subject to heavy loads in long-span steel structures, because typical welded and bolted

connections were unable to meet the design criterias (see Figure 1). This pin-connected joint was designed to meet some requirements such as simple, durable and achievable with higher construction speed and less on-site weldings. Moreover, the proposed joint aimed to match the development trend of “green buildings”, which was an energy saving and eco-friendly policy introduced by local authorities towards lowering carbon footprint[8].

However, although pin connection has a large number of applications in China, there are few specifications prescribed on this type of connections, and the experimental and analytical study data are limited[9]. Besides, standards from other countries, including European[10], American [11]and Australia standards [12], are recommended in the design of pin-connections. Therefore, it is necessary to conduct a detailed research to investigate the static and seismic performances of this connection and provide provisions for the design of pinned connections..

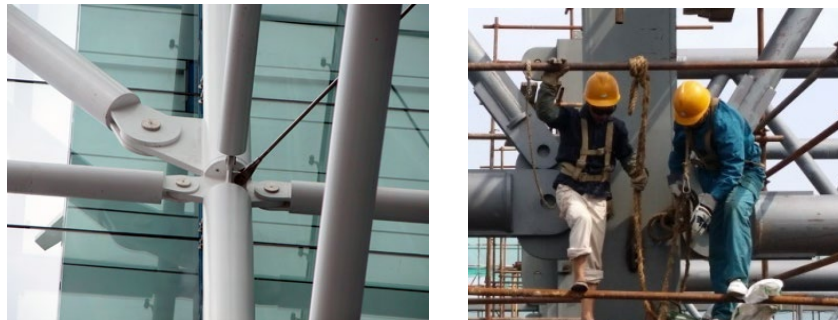


Fig. 1. Application of Pin-connected Joints

Structure of the Joints

In order to study the behaviour, four specimens including two full-scale and two large-scale models were designed as per current Europe design code and tests were conducted under static and quasi-static loads. The test results would be compared with the corresponding finite element analyses. For the construction, pin-connection joints consisted of ear plates and pin shafts which were welded together in the factory; the trusses and columns were connected by pin-connections on-site by high-strength shafts[13].

Experimental Study

Specimen Design. Four pinned connection specimens called as JD1–JD4 were constructed and tested under monotonic and cyclic loadings. Test scales were determined as 1/2-scale on JD3 and JD4 and full-scale specimens on JD1 and JD2, since the strength constraints and geometric of existing laboratory conditions. The details of the pinned connection specimens are shown in Figure 2.



(a) JD1 and JD2

(b) JD3 and JD4

Fig. 2. Details of the Test Specimens

Loading Plan. Specimens JD1, JD2 and JD3 were subjected to constantly monotonic static loads at the top; cyclic loads were imposed on specimens JD4. The axial load was applied and maintained constantly by a hollow-core-hydraulic jack and reaction frame of which capacity is 2000kN. All tests were carried out at a laboratory atmosphere of $20\pm 5^{\circ}\text{C}$ room temperature and $50\pm 10\%$ relative humidity. The test instruments are seen in Figure 3.



Fig. 3. Test Setup for JD1, JD2, JD3 and JD4

Loading System. This test has two kinds of loading systems: specimens JD1-JD3 were subjected to monotonic tensile loading; the specimen JD4 was subjected to cyclic loading.

Monotonic Loading. Monotonic loading was adopted for the static tests with the load at a level until the specimen failed. Monotonic loading, the load control method, was divided into three stages of loading: Nominal load increasing by 10% to 100%; ultimate load increasing by 10% to 100%; fail load increasing 150%~200% nominal load until failure.

Cyclic Loading. According to Chinese standard test method, the quasi-static loading procedure adopted the method of double controlling: the whole loading process was controlled by loading before yield and displacement after yield. But because the test specimens were special, there was a gap for the pin connection, so it was very difficult to control the displacement. Therefore, load control method was applied during the whole test loading. Figure 8 shows the loading system as follows:

- (1) test could no longer be carried if sudden damage occurred or sudden loss of stability occurred;
- (2) the load of each level in the elastic stage was 200kN with 2 cycles ;
- (3) the load of each level in the plastic stage was 200kN with 2 cycles until the specimen failed.

Experimental Results

The yield load P_y , the ultimate load P_u , the yield displacement Δy , and the ultimate displacement Δu at the loading points were obtained by the results of the test. The four specimens' failure modes were familiar, which include three types: weld fracture of the ear plates, buckling at the chord members, and deformation of the shaft.

(1) Specimen JD1

This specimen was designed to be tested under a pull load only. The elastic deformation was approximately 3.7 mm, and the plastic deformation was around 8.3mm. Damage occurred in the ear plate weld (see Figure 4). The pin shaft deformation was about 1.2mm when the ear plate cracked. During the test if the ear plate welding pin was not destroyed, the ultimate bearing capacity could be improved. It can be seen from Figure 11 that the ultimate load of Specimen JD1 is 9297kN that is 2.21 times of design value. The load-displacement curve of the loading point is given in Figure 4.

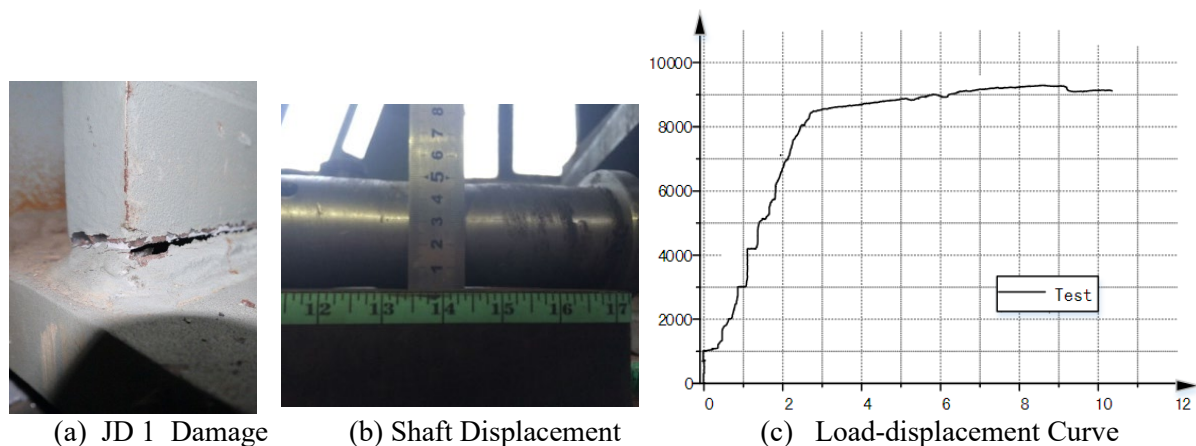


Fig. 4. Failure, Shaft Deformation and Load-displacement Curve for Specimen JD1

(2) Specimen JD2

This specimen was designed to be tested under a push load only. The behavior of the specimen was completely different under push loading. The maximum push loads were 5.82 times of design value. The capacity under pull loading was much larger than it was under push loading. Specimen JD2 showed different mechanisms to resist the pull and push loads. No apparent damages occurred in this specimen. The maximum displacement of pin shaft was approximately 12 mm when the ear plate touched the steel plate of members (as shown in Figure 5).

The load-displacement curve of the loading point is presented in Figure 5.

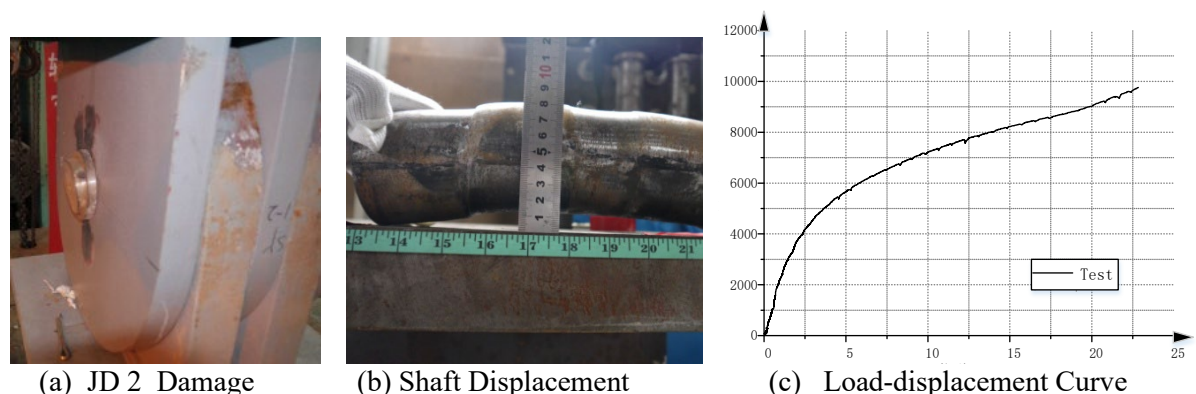


Fig. 5. Shaft Damage, Deformation and Load-displacement Curve for Specimen JD2

(3) Specimens JD3

The bearing capacity was determined in specimens JD3 which was a part of the whole truss under the monotonic loading. It can be seen from Figure 6 that the ultimate carrying capacity of Specimen JD3 outperformed Specimen JD1 and JD2. The ductility performance of the specimens did not significantly reduce its carrying capacity in term of non-elastic deformation capacity. The weld quality significantly affected the ductility of the joints as well as energy dissipation. When Specimen JD3 reached the ultimate load, the carrying capacity had little reduction. It was clear that the existence of truss members improves the ductility of the pinned connection.

The load-displacement curve of the specimen JD3 is illustrated in Figure 6. Specimens JD3 was not damaged mainly because of limited loading device, as shown in Figure 6. The maximum displacement of pin shaft reached 5.6mm.

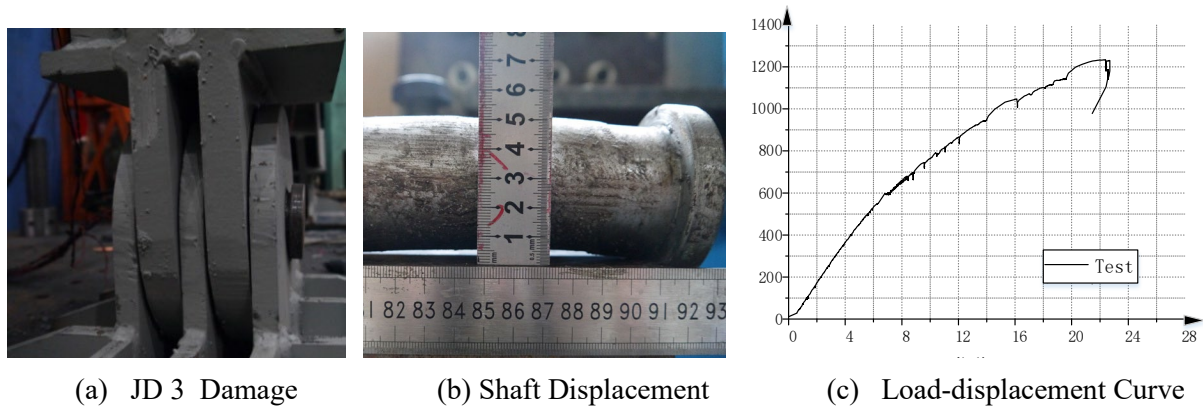


Fig. 6. Shaft Damage, Deformation and Load-displacement Curve for Specimen JD3

(4)Specimens JD4

The experimental lateral load–displacement curve, which represents the seismic behavior of structures, is a very important factor under cyclic loading. The area, surrounded by this curve, represents the energy-dissipation ability of the structure.

It can be seen from the test results, the specimen loading showed obvious asymmetry, especially after entering the plastic phase. The reason was the significant deformation of some components out of plane. But the test studied the tensile behavior of the member, the hysteretic curve of the tensile loading was very full, smooth, which indicated that they had better ductility and energy dissipation. Table 1 gives the main results.

Table 1. Measure Results

Sample	Load (KN) (+)	Dis. (mm) (+)	Load (KN) (-)	Dis. (mm) (-)	Load (KN) (+)	Dis. (mm) (+)	Load (KN) (-)	Dis. (mm) (-)
JD4	200	5.5	200	3.87	200	4.95	200	3.53
	400	6.3	400	6.42	400	7.11	400	5.39
	600	8.97	600	7.35	600	9.59	600	7.05
	800	14.9	800	9.25	800	14.01	800	0.02
	1000	22.7	1000	12.94	1000	22.97	1000	13.13
	1200	33.0	1200					

The hysteretic curve is provided in Figure 7. The damage of specimens JD4 occurred in the 1200kN load cycle on second lap for the buckling of member's winging, as seen in Figure 7. The maximum displacement of pin shaft reached 1.5mm.

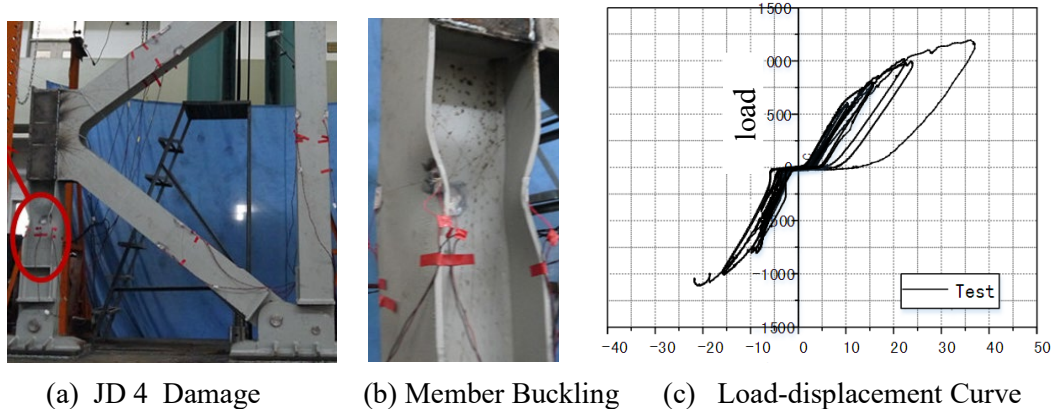


Fig. 7. Shaft Damage, Deformation and Load-displacement Curve for Specimen JD4

Conclusions

The behavior of pinned-connection joints subject to monotonic static loading and cyclic loading was investigated. Four pinned-connection specimens were studied in the tests and finite element analysis. Finite element analysis results were compared with those of experimental results. The main conclusions are summarized as follows:

- (1) The welding seams between the chord members and the ear plates significantly affected the failure mode and various mechanical properties of the pinned-connection joints. Sudden fractures of the welding seams resulted in a decrease in the plastic deform ability of the pinned-connection joints. To obtain seismic energy dissipation requirements, strengthen the ear-plate thickness was recommended and increased the lengths of the welding seams to avoid generating cracks under load.
- (2) The hysteretic curve shapes were full and smooth, and the load–displacement curves, which represent suitable ductility and energy dissipation ability, had gently descending stages, the pinned-connection joints showed good seismic performance, ductile performance and energy dissipation capacity.
- (3) The results of the simplified calculation formulas proposed in the Europe code got along well with that of the model test and the finite element analysis. The formulas could be used to describe the strength of joint under static load and cyclic load. The results indicate that the proposed pin connection is viable and can be applied to truss-column joint in long-span steel structures.

Further studies, such as response of the whole structure and multi-scale modelling, may be required although this structural system had been used in practice. However, research on the dynamic behavior of pinned-connection joints systems as well as study to improve the details will be carried out by the author for further investigation.

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