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Experimental Study on hysteretic behaviour of tubular N-joints

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ABSTRACT

Tubular joints are often adopted in CHS structures due to their simple and aesthetic appearance. The ultimate load carrying capacity of this kind of joint has received lots of attention in the past 30 years. However, little research work has been carried out on their hysteretic behavior. In this paper, the hysteretic behaviour of tubular N-joints was studied experimentally. Four specimens were built and tested under quasi-static cyclic loads. They are unstiffened tubular N-joint, doubler plate reinforced tubular N-joint, tubular N-joint with concrete filled chord member and doubler plate reinforced tubular N-joint with concrete filled chord member. The failure modes of the four specimens under cyclic loads were observed during the tests. The hysteretic curves obtained for all the four specimens are plump and stable. Based on the hysteretic curves, the ductility ratio and the energy dissipation ratio were evaluated and compared for the four specimens. The ultimate load carrying capacities of the specimens determined from their skeleton curves are also discussed and compared.

1. Introduction

Circular hollow sections (CHS) are widely used in steel structures for their structural efficiency [1]. On land, they are found in structures such as towers, bridges, and long-span roof structures and offshore they are employed in platform jackets. In most of these CHS structures, unstiffened tubular joints are adopted due to their simple and aesthetic appearance. With unstiffened tubular joints, the CHS members are joined together by welding the profiled ends of secondary members, the braces, onto the circumference of the main member, the chord. The behaviour of these unstiffened tubular joints, even in their simplest configuration, is complex and difficult to analyze in practical design.

The behaviour of unstiffened tubular joints has received lots of attention in the past 30 years. Extensive research has been done on the ultimate load carrying capacities of unstiffened tubular joints with different configurations [2–5]. Design equations based on theoretical and experimental studies have been recognized by related codes [6,7]. However, little research has been carried out on the hysteretic behavior of unstiffened tubular joints. Different from common joints used in steel frame structures, ultimate load carrying capacities of unstiffened tubular joints are often lower than those of the brace members. Under the action of severe earthquakes, yielding and local buckling may occur first in the joint region and the hysteretic behavior of the joints will affect the overall seismic performance of the structures. Therefore, a full understanding of the hysteretic behavior of unstiffened tubular joints is necessary for rational seismic design of CHS structures using this kind of joint [8,9].

To improve the ultimate load carrying capacity of unstiffened tubular joints, various approaches are available. Reinforcing the unstiffened tubular joints with a doubler plate is very cheap and more convenient to fabricate, where the profiled braces are first welded to the doubler plate through a penetration weld and the doubler plate is then welded to the chord outer surface through fillet welds along its edges. An alternative approach is using concrete filled CHS for the chord member if the weight of the concrete causes little stress in the structure members. Both the approaches were proved effective in improving the ultimate load carrying capacity of unstiffened tubular joints [10–13]. However, since the deformation of the chord wall is restricted by the doubler plate or the in-filled concrete, the hysteretic behaviour of the reinforced joints will change and need to be studied in detail.

In this paper, the hysteretic behaviour of a typical tubular N-joint, as show in Fig. 1, was studied experimentally. Four specimens were built and tested under quasi-static cyclic loads. They are the unstiffened tubular N-joint, doubler plate reinforced tubular N-joint, tubular N-joint with concrete filled chord member and doubler plate reinforced tubular N-joint with concrete filled chord member. The failure modes of these specimens under cyclic loads were observed during the tests. The hysteretic curves and skeleton curves were obtained for the four specimens in the tests. Based on the hysteretic curves, the ductility ratio and energy dissipation

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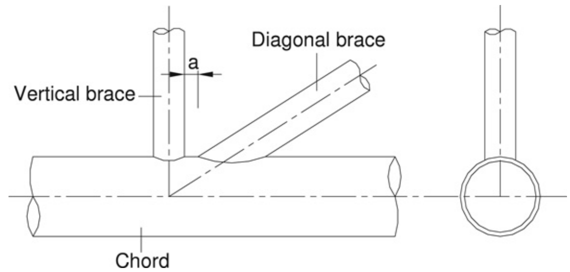

Fig. 1. Typical unstiffened tubular N-joint.

Table 1
Test specimens

Specimens	Material	Chord	Brace	Doubler plate	Infilled concrete
JD-A	Q345B	$\Phi 245 \times 6$	$\Phi 89 \times 6$	–	–
JD-B	Q345B	$\Phi 245 \times 6$	$\Phi 89 \times 6$	$t = 6$	–
JD-C	Q345B	$\Phi 245 \times 6$	$\Phi 89 \times 6$	–	C50
JD-D	Q345B	$\Phi 245 \times 6$	$\Phi 89 \times 6$	$t = 6$	C50

ratio of the joints were evaluated and compared. The ultimate load carrying capacities of the joints determined from the skeleton curves are also discussed and compared.

2. Test specimens

Four specimens were built for the quasi-static cyclic tests. They are the unstiffened tubular N-joint, doubler plate reinforced tubular N-joint, tubular N-joint with concrete filled chord member and doubler plate reinforced tubular N-joint with concrete filled chord member, as shown in Table 1. All the four specimens are of the same configuration with the chord member $\Phi 245 \times 6$, brace members $\Phi 89 \times 6$ and the angle between the diagonal brace and the chord being 45°. The gap size is a = 15 mm, as shown in Fig. 1. Some geometrical parameters of the specimens are $\beta = d/D = 0.36$, $\tau = t/T = 1.0$ and $\gamma = D/(2T) = 20.4$, in which D and T are the outer diameter and wall thickness of the chord, d and t are the outer diameter and wall thickness of the braces.

The schematic of the tubular N-joint test specimens is as shown in Fig. 2. The length of the chord is 1750 mm, which is approximately seven times the chord diameter. The net lengths of the two braces are approximately five and seven times the brace diameter respectively. The doubler plate is 340 mm long and 205 mm wide. The plate thickness is 6 mm, the same as the thickness of the chord wall. There are end plates and stiffeners at all ends of the chord and the braces, through which the specimens can conveniently be bolted to the test setup.

The chord, the braces and the doubler plates in the four specimens are all of Q345B steel [7]. The grade of the steel was confirmed by tension coupon tests. The material properties obtained from the tension coupon tests satisfy the requirement of Q345B steel and are summarized in Table 2. The concrete filling the chord of specimens JD-C and JD-D is C50 concrete [14]. Some material properties of the concrete are as shown in Table 3.

3. Test setup and loading procedure

Since low-cycle cyclic loads are applied to the specimens during the quasi-static tests, the test setup should have enough strength and stiffness to subject loads of opposite directions.

The specially designed test setup is as shown in Figs. 3 and 4. The main component of the test setup is the reaction girder at the bottom. The girder is composed of two H-shaped steel sections connected to each other with high strength bolts. The girder is supported on the ground through three steel blocks to transfer vertical compression, and anchored to the slots in the ground through three sets of crossbeams, jacks and steel bars to transfer the vertical tensile force. One end of the girder is supported and anchored to the reaction wall to transfer horizontal tension and compression forces. The specimen stands on the reaction girder as shown in Figs. 3 and 4 with the chord perpendicular to the ground. The bottom end of the chord and the free end of the diagonal brace are pinned to the reaction girder. A self-controlled hydraulic actuator is bolted to the free end of the vertical brace to apply the load. The load capacity of the actuator is 1000 kN in tension and compression. When the actuator pushes, the vertical brace is in compression (N_1) and the diagonal brace reacts axially in tension (N_2), as shown in Fig. 5(a). When the actuator pulls, the vertical brace is in tension (N_1) and the diagonal brace reacts axially in compression (N_2), as shown in Fig. 5(b). With the actuator pushing and pulling repeatedly, cyclic loads can be applied to the specimens in the tests. In this paper, positive signs are taken for tensile forces while negative signs are taken for compression forces.

For each specimen, a total number of ten 3-dimensional strain rosettes were mounted on the chord wall around the intersections between the chord and the braces to measure the strain distributions at these hot spots. To determine the axial forces in the chord and braces and verify the loading condition of the tests, additional strain gauges were mounted on the chord and braces. Eight evenly spaced strain gauges were mounted on the outer surface of each member. Four LVDTs were used in the tests to measure the displacements at selected key points. The general arrangement of strain rosettes, strain gauges and LVDTs is as shown in Fig. 6.

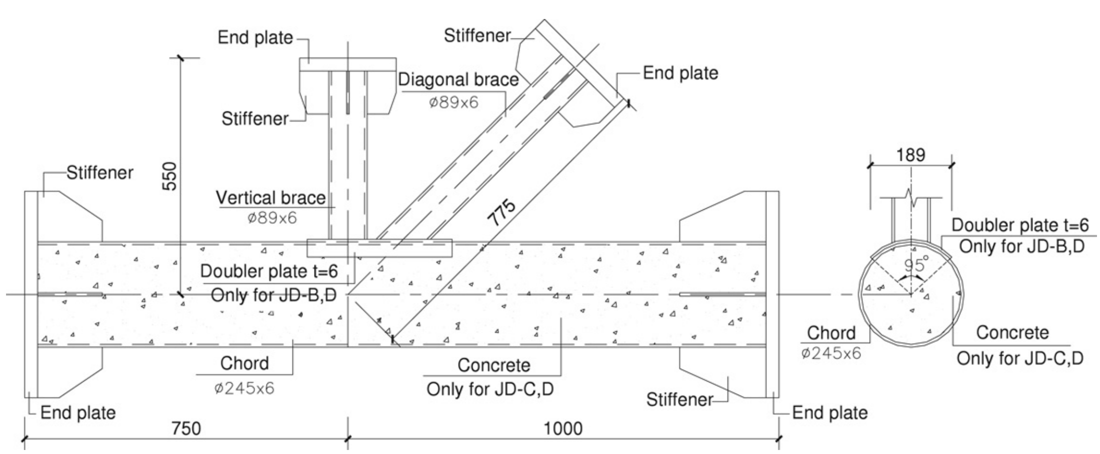

Fig. 2. Test specimens.