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Experiment study on hysteretic behaviour of arch truss

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Experiment study on hysteretic behaviour of arch truss

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Abstract. The research carries pseudo-static test on 6m- span spatial arch truss specimen with three centers under vertical circle loading, and analysis on their failure process. The hysteretic loops, skeleton curves and stiffness deterioration is obtained. The experimental results showed that the failure of arch truss specimens starts buckling and cracking of lower chord, then the members gradually formed local cracking in this region, and finally the midspan with the greatest force cracking leads for the truss to form geometrical mechanism and collapse; When the structure fails, many members enter the plastic stage. The overall plastic deformation is large and the energy consumption performance is good.

1. Introduction

At present, large-span steel structure is widely used in sports venues, convention and exhibition centers, stations, docks and airports, ect. In previous earthquakes, such buildings have often become refuge for victims, like Jiuzhou stadium in Wenchuan earthquake and stadiums and gymnasiums of schools in East Japan earthquake[1-2]. Because the joints in steel pipe structure damage cause some members which are connected with them lose efficacy, then the whole structure destroys. So a great deal of experimental study and theoretical research of connecting nodes of members bars has been done by scholars at home and abroad[3-9]. However, although the ultimate bearing capacity of joints in steel-tube structure is directly related to the reliability of the whole structure, the force of the joint can not fully reflect the mechanical behavior of the structure. At the same time, it can not get the effect of node failure on structural failure. Thus, this paper study the quasi-static test of a 6m-span three-center steel tube spatial arch truss model and get the whole process of structural failure.

2. Test Situation

The 6m-span spatial arch truss specimen with three centers is symmetric about middle span. The shape of section is inverted triangle. Both upper chord and lower chord are lengthen steel pipe. The section of the upper chord is $\phi75.5\times3.5$, the lower chord is $\phi88.5\times3.75$ and the web members and the diagonal bracings are $\phi60\times3.25$. All of the members are welded tubular joints. Three lateral support junction points are set up in middle span and tangent point of elevation. The thickness of top plates is 22mm and of the ribbed plates is 10mm. The specimen structure is shown in the Figure 1. All steel pipes of spatial arch truss are high frequency welded pipe, and the material is Q235B. Material properties are measured by uniaxial extension test, as shown in table 1. The loading device of spatial arch truss is shown in Figure 2. Three out-of-plane restraint brackets are set up in order to prevent out-of-plane distortion. The loading method references *Specificating of testing methods for earthquake resistant building* (JGJ101-96) [10]. At load control stage, the tests were first applied 10KN and conducted under load increment of 10KN for three load cycles. At displacement control stage, the yield displacement **Δy** which is correspond to the first yield member of the structure is the reference displacement. The tests were applied displacement increment 0.5**Δy** for six cycles in every displacement degree until the failure of the structure. According to numerical simulation analysis results, the members were set up 104 strain measurement points, eight displacement meter measuring points and two dial indicator measuring points. The numbers and positions of measuring points are shown in Figure 3.

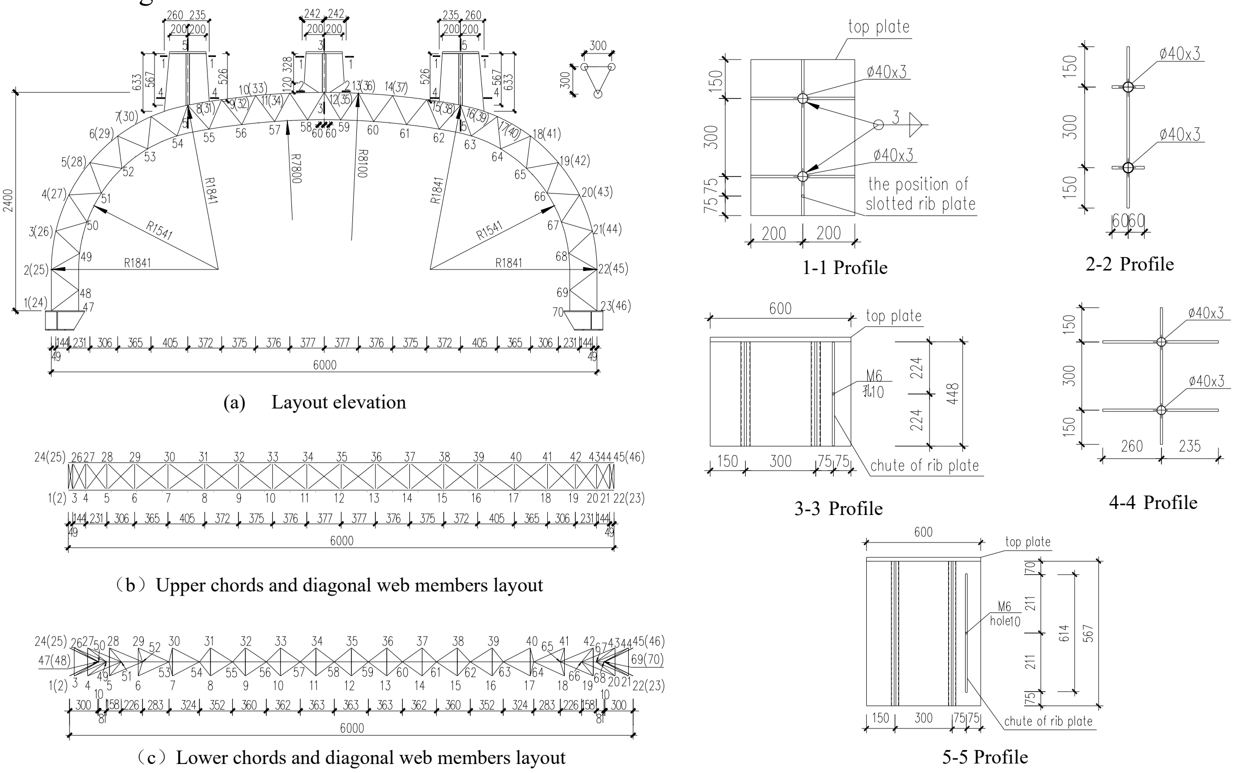


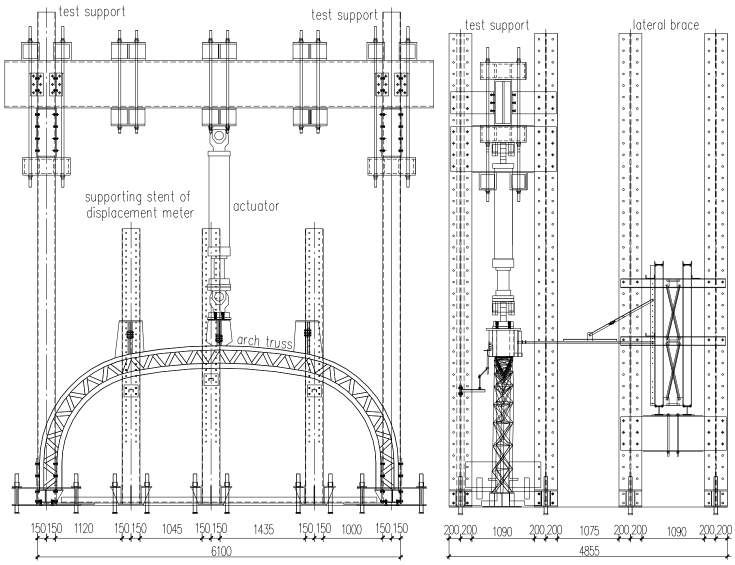
Figure 1. Structural diagram of test specimen

Table 1. Mechanical properties of steel pipe

Steel pipe	Yield strength *fy*(MPa)	Tensile strength *fu*(MPa)	Elastic modules *E*(MPa)	Poisson's ratio *ν*
*ϕ*60×3.25	495	506	1.66×10^5	0.25
*ϕ*75.5×3.5	394	450	1.79×10^5	0.30
*ϕ*88.5×3.75	389	462	1.86×10^5	0.27

3. Test phenomenon

The destruction sequence and position of the test specimen nodes and member bars are shown in Figure 4. In the process of initial loading to controlling displacement 36mm, the specimen underwent elastic and elastoplastic development. The loading displacement 40mm when the first cycle is drawn, nodes 58-59 in span centre, the lower chord lower part suddenly appears flection distortio, as shown in Figure 5(a). As the number of cycles increased, cracks appeared and gradually developed. Tension fracture completely appeared here at sixth cycle pushing, as shown in Figure 5(b)(In Figure 4, ①). In the process of displacement 44-56mm, the shear Angel of the loading support and the connection between the spatial arch truss span centre and upper chord of the spatial arch truss successively appeared cracks, as shown in Figure 5(c)(In Figure 4, ②,③,④). The loading displacement 60mm when the first cycle is pressure, cracks begin to appear in the lower part of the upper chord 12 and 35 node, and continued to develop during the loading process. The loading displacement 76mm when the first cycle is drawn, The end section of the lower right chord on node 64 is suddenly pulled and necked, as shown in Figure 5(d)(In Figure 4, ⑤). In the meantime, there is a sudden buckling deformation in the middle of lower chord between 53 and 54, as shown in Figure 5(e)(In Figure 4, ⑥). In the subsequent cyclic loading process, cracks appear at the intersection of two upper chord nodes with the lower chord on the right side of node 64, as shown in Figure 5(f)(In Figure 4, ⑦). The upper side of the pipe wall at the end of the lower chord on the right side of node 53, as well as the intersection of the two node upper chords and the buckling part of the same joint, showed cracks gradually developing, as shown in figure 5(g)(In Figure 4, ⑥,⑧,⑨). The loading displacement 110mm when the first cyclic pressure, node 12 breaks(In Figure 4,⑩). At the first cyclic pressure of 130mm, node 35 break(In Figure 4,⑪). The structure has been invalidated and became a mechanism as shown in figure 5(h).



(a) Front elevation (b) Side elevation

Figure 2. Test specimen loading equipment

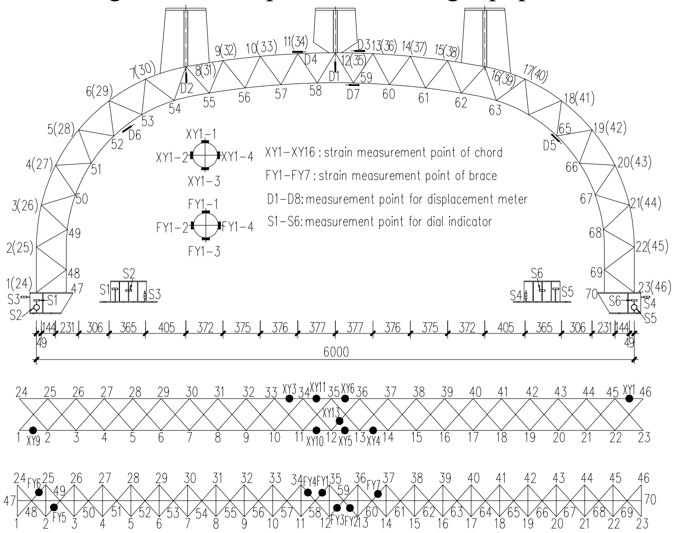


Figure 3. Measurement position of test specimens

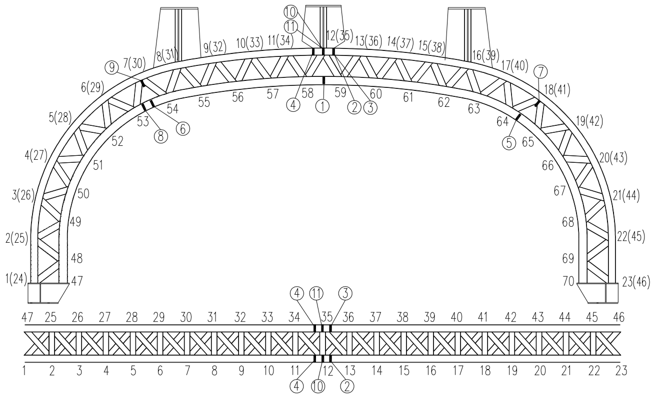


Figure 4. Failure sequence and location of specimens

(a)Span centre lower chords buckling

(b)Cracking of lower chords in span

(c)Crack of upper chords in loading bearing

(d)Lower chord end crack on the right-side of node 64

(e)lower chord buckling between node 53 and 54

(f) Web member intersection crack between node 18 and 41

(g)Crack developing between node 53 and 54

(h) span centre upper chord node break

Figure 5. Specimen failure

4.Test results and analysis

4.1 The hysteretic loops

The hysteretic loops of spatial arch truss specimen under cyclic loading "Mid span vertical load P-joint vertical displacement △" is shown in Figure 6. In the figure, take push as positive and pull negative. It can be seen from the hysteretic loops: When the load is small, the load is linear with displacement, indicating that the structure is in the elastic stage; as the loading displacement increased, the relationship between load and displacement gradually changed into a spindle curve, indicating that the member bars in structure keep coming into the elastic-plastic phase and began to consume energy; during the lower chord in the structure from buckling to breaking, the hysteretic loops substantially falls to the displacement axis, and finally stay at the new equilibrium position and continue to bear lower load; with the successive failure of structural members, the hysteretic loops gradually falls to the displacement axis and the areas it decreases accordingly, and energy dissipated is gradually reduce.

4.2 The skeleton curve

The skeleton curve of spatial arch truss specimen is shown in Figure 7. As can be seen from the figure, the load and displacement show a linear relationship during the elastic stage; In yield strengthening stage, deformation modulus decreases gradually with the increase of loading displacement, until to ultimate bearing capacity; in bearing capacity degradation stage, because of member bars broken, deformation modulus abruptly reduces in the ultimate bearing capacity point. Another member bars break one after another and bearing capacity is decreasing until the structure loses efficacy.

4.3 The stiffness degradation

The stiffness degradation is a phenomenon because of the slope of connection between coordinate origin in hysteretic loops and some cyclic load peak deteriorates with the increase of displacement. The Figure 8 shows the stiffness degradation curve of spatial arch truss specimen. As shown in the figure: stiffness will decrease with the increase of the number bars entering plastic and the development plastic. When some member bar cracks or break, the stiffness of structure will decrease greatly.

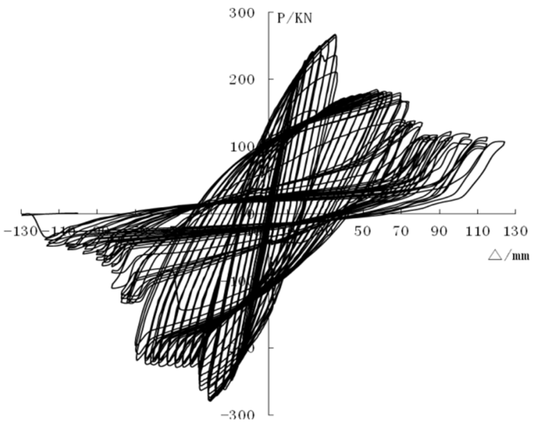


Figure 6. Hysteretic loops of specimen

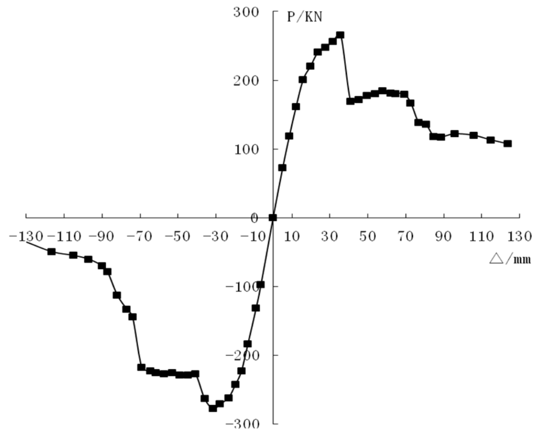


Figure 7. Skeleton curve of specimen

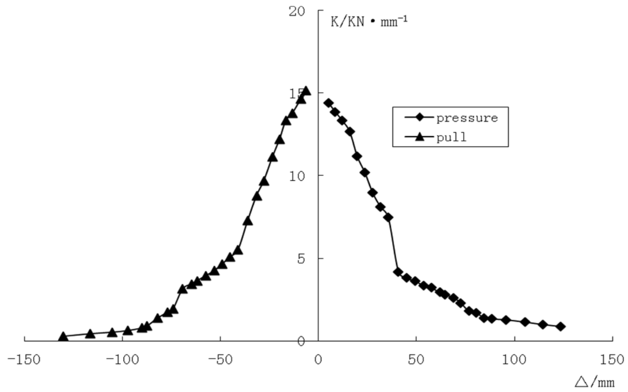


Figure 8. Stiffness degradation curves

4.4 The destruction characteristics

The test results show that spatial arch truss structure reaches the ultimate bearing 277KN under span centre cycle loading and loading pushing displacement 36mm in the first cycle. The ratio of measured displacement of span centre to span is 1/190, under small elastic-plastic deformation and no obvious global deformation circumstances, the member bars have buckling and fracture destroyed; however, the ratio of deflection of span centre to span is 1/46 when the structure is destroyed. The overall deformation of the truss is obvious and elastic-plastic deformation is very large. This indicates most member bars enter the plastic stage when destroy and the dissipation of structure is good. The structure is ductile failure and the residual load bearing is large.

5.Conclusion.

(1)The failure process of spatial arch truss under span centre concentrated cyclic loads: the maximum force between joints (mid and lower span chord) suddenly buckling and breaks through 6 cycles. The structure change from space arches to plane arch and the stiffness drops rapidly; With the increase of load, the member bars in the span centre are destroyed one after another, and the bars near the tangential of the lower chord of the arch truss with different centers were destroyed successively. The bearing capacity of structure continues to decline so the dissipation declines.

(2) In the initial stage of loading, only some of the members of the arch truss successively enter the elastic-plastic state. With load increasing, other member bars and joint connecting places appear cracks and break. When the structure fails, more members enter the plastic stage so the overall deformation of the structure is very large and the dissipation capacity is good.

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