Experimental Research on Seismic Performance of Four-Element Variable Cross-Sectional Concrete Filled Steel Tubular Laced Columns

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Abstract. A total of 7 experimental tests were conducted to investigate seismic performance of four element variable cross-sectional Concrete Filled Steel Tubular (CFST) laced columns. The experimental parameters are longitudinal slope and arrangement type of lacing tubes. The rules on hysteresis loop, ductility, energy expenditure, and stiffness degradation of specimens are researched. Test results indicate that all specimens have good seismic performance; their hysteresis loops are full without obvious shrinkage. With the increase of longitudinal slope, the horizontal carrying capacity increases, energy dissipation capacity improve, and there is slightly increase in stiffness degradation. The influence of arrangement type of lacing tubes on displacement ductility of specimens is big.

1. Introduction

Variable cross-sectional Concrete Filled Steel Tubular (CFST) laced column consist of CFST longitudinal elements tied together using steel lacing tubes, the section size of column is gradually increasing from top to bottom. Compare with equal sectional laced column, variable cross-sectional laced column is advantageous in relatively high compressive strength capacity, relatively high horizontal bearing capacity, good overall stability, excellent deformation capacity and attractive appearance. Furthermore, this type of hybrid column has more excellent earthquake resistance for its center of gravity is lower and the reaction of the column under earthquake function is decreased [1]. So it is believed that there is great potential to apply variable cross-sectional CFST laced columns in high-pier bridges, equipment frame and large-span CFST truss arch bridges located in strong earthquake region.

Examples of such structures include Ganhaizi super large bridge in Sichuan province in China [2]. It crosses seismic belt (Magnitude=9), the overall length is 1811m, and it is the longest total CFST truss girder bridge in the world. In the substructure of the bridge, CFST laced column and CFST hybrid columns are used according to different pier height. In which No. 26 pier is 67.29 meters high, the longitudinal slope is 1:50, and it is the tallest variable cross-sectional CFST laced column pier in the world.

In recent years, several investigations have been performed to quantify the dynamic behavior of CFST columns. Some researchers have focused on the seismic performance of CFST single longitudinal column and same cross-sectional CFST laced columns [3]-[11]. However, seldom research has been conducted on aseismic behavior of variable cross-sectional CFST laced columns, and additional experimental results are needed to quantify the hysteretic properties, ductility, failure mode and horizontal load-carrying capacity of these CFST laced columns.

In this paper, the pseudo-static test of 7 specimens was conducted to investigate seismic performance of four-element variable cross-sectional CFST laced columns, with the experimental parameters of longitudinal slope and arrangement type of lacing tubes. The rules on hysteresis loop, skeleton curve, ductility, energy expenditure, and stiffness degradation of specimens are researched, then failure mode failure mechanism are discussed. These experimental results can provide research basis for dynamic characteristics analysis and seismic design theory of variable cross-sectional CFST laced columns.

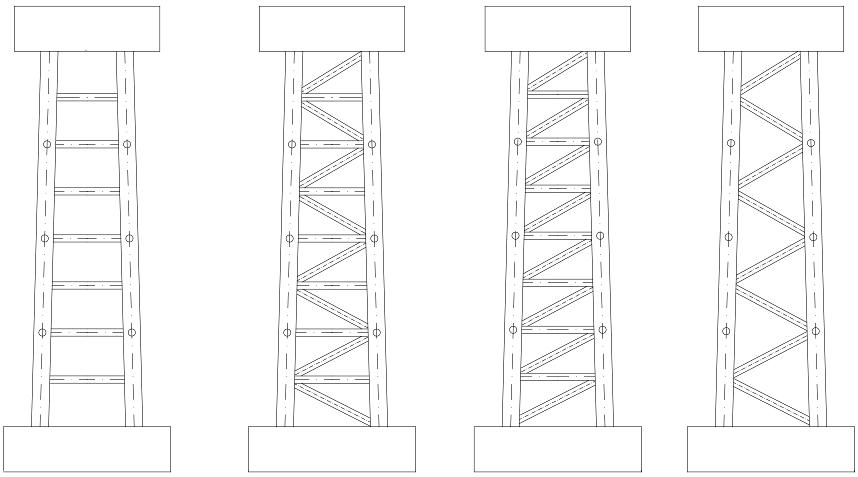
2. Specimens

Seven 1/8-scale specimens were designed and fabricated taking No.9 pier of Ganhaizi super large bridge as the prototype, include six laced column with inclined lacing tube and one laced column with flat lacing tube, as shown in Table.1. They had same section dimension and same length of 2.5 meter, outer center distance of longitudinal element is 700mm, inner center distance of longitudinal element on the top section of column is 0.3, inner center distance of longitudinal element on the bottom section of column is decided according to longitudinal slope. The axial compression ratio is 0.15.

Each specimen was composed of four longitudinal CFST members (φ114×2mm steel tubes filled with concrete C50) and several lacing steel tubes ofφ48×2mm. Seven specimens designated as BP-1 to BW-2, corresponding to experimental parameter of longitudinal slope and arrangement type of lacing tubes, which were listed in Tab.1. Longitudinal slope is set at 1:40 and 1:20, the layout of the tubes is respectively made up of flat, K, N and W, as shown in Tab.2.

Table.1 Characteristics of Test Specimens

Specimen	arrangement type of lacing tube	longitudinal slope	Peak load (kN)
BP-1	Flat	1:40	80.11
BK-1	K-type	1:40	201.09
BN-1	N-type	1:40	179.23
BW-1	W-type	1:40	213.39
BK-2	K-type	1:20	209.02
BN-2	N-type	1:20	208.21
BW-2	W-type	1:20	236.39



(a)Flat (b) K type (c) N type (d) W type

Figure.1 arrangement type of lacing tube

From the tests of the materials used in the specimens, the yielding strength f_s of the longitudinal steel tube and lacing tube are 365MPa and 384MPa, respectively, and elastic modulus E_s is

2.06×105MPa, the standard value of curb strength of the concrete fck is 59.4MPa, its elastic modulus Ec is 3.45×104MPa.

3. Experimental method

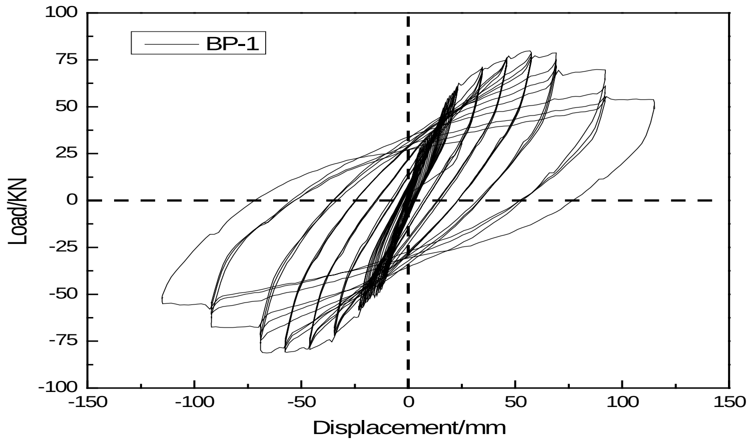
All specimens are tested by MTS servo loading system. Pseudo static loading scheme is adopted, the constant vertical load is applied by hydraulic jack on top of pier to control axial load ratio of the specimen. Then horizontal load (low reversed cyclic displacement) is acted by horizontal jacks fixed on the counterforce wall. The testing set-up is shown in Fig.2. Displacement control is adopted in load mode. After the specimen yielded, load step was changed to multiples of yield displacement. When cyclic loading dropped to 85% of peak load, test was stopped. The specimens were instrumented to measure (a) strain of longitudinal member at the bottom and mid-height section in both longitudinal and transverse direction; (b) strain at lacing tubes' middle section;(c) deformation in longitudinal and lateral axial.

Figure.2 Test device

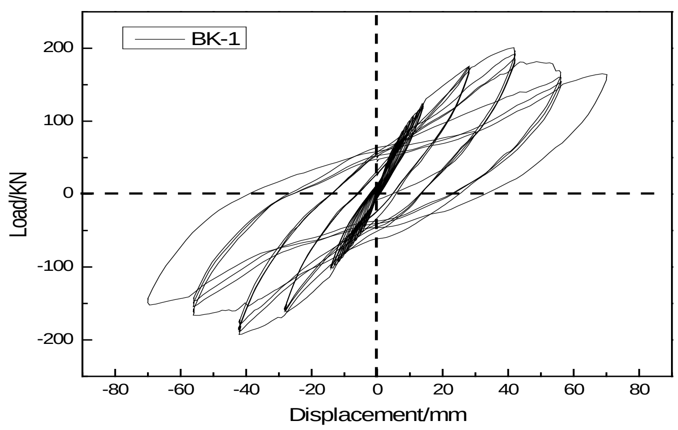
4. Experimental results

4.1 Load-displacement hysteretic loop

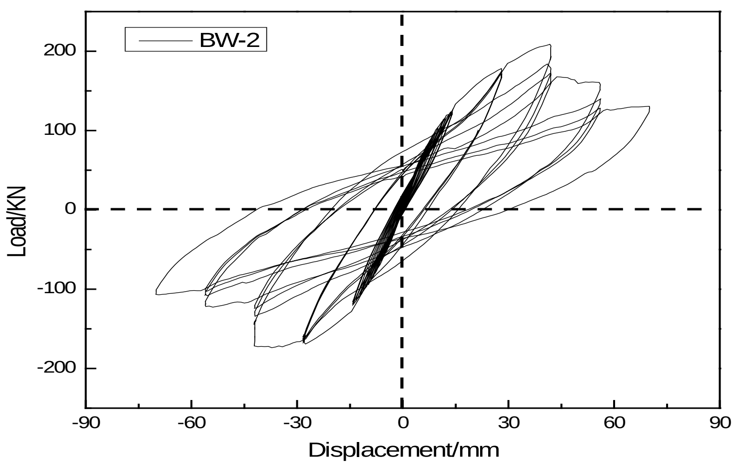
The load-displacement hysteretic loops of typical specimens are shown in figure 3. The hysteretic curves of each specimen are relatively plump fusiform and there is no obvious pinch, it shows that variable cross-sectional CFST laced columns have good seismic performance, they can absorb and dissipate seismic energy well. Comparing these curves, it can be found that fullness degree of CFST laced column with flat lacing tube's hysteresis loop is evidently bigger than that of CFST laced column with inclined lacing tube.



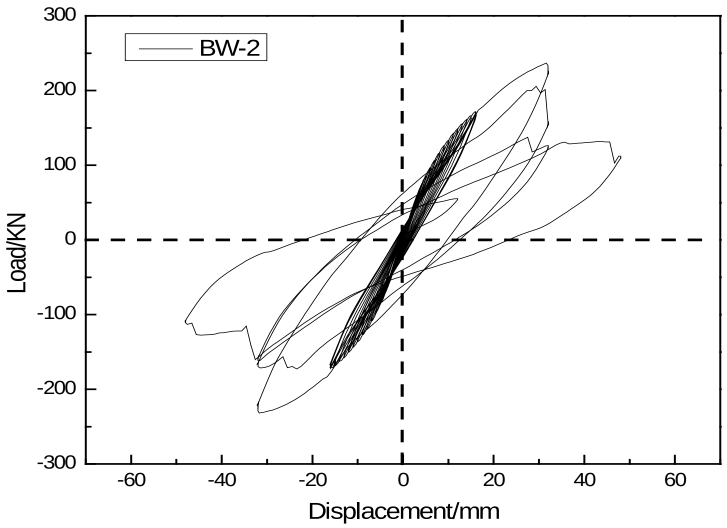
(a)BP-1 specimen



(b) BK-1 specimen



(c) BN-2 specimen



(d) BW-2 specimen

Figure.3 Comparison of load-displacement hysteresis loops

4.2 Load-displacement skeleton curve

The load-displacement skeleton curves of typical specimens are shown in figure 4, these laced columns have same longitudinal slope (1:40) and different arrangement type of lacing tubes. From Fig.3, it can be found that elastic stiffness and horizontal peak load of CFST laced column with inclined lacing tube (specimen BK-1, BN-1, BW-1) are obviously larger than that of CFST laced column with flat lacing tube (specimen BP-1). Because the lacing tubes and longitudinal elements form a stable triangle relationship in variable cross-sectional CFST laced column, thus the overall performance of the specimen evidently improved, and the stiffness and bearing capacity increase accordingly.

The skeleton curves of specimens with N-type lacing tubes are shown in figure 5. It can be found that with the increase of longitudinal slope from 1:40 (specimen BK-1) to 1:20 (specimen BK-2), the elastic stiffness and horizontal peak load increase 16.7% and 16.2%, fall-period stiffness and ultimate displacement are respectively nearly.

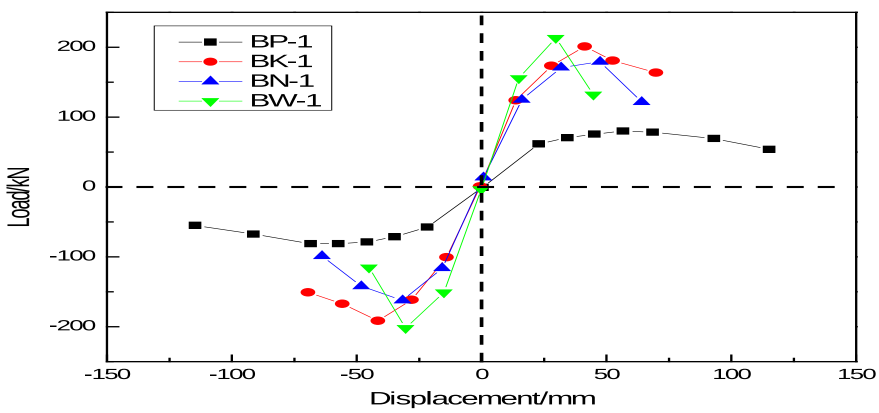


Figure.4 Skeleton curve with different lacing tube type

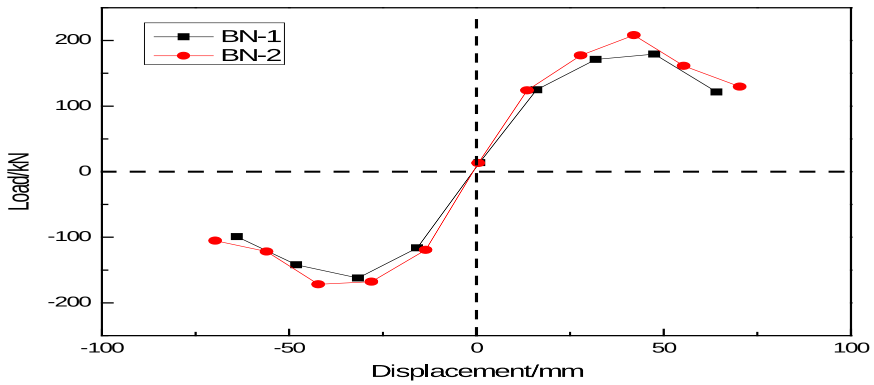


Figure.5 Skeleton curve with different longitudinal slope

4.3 Ductility

Ductility is one of the important indexes to evaluate seismic performance, it can be expressed by displacement ductility coefficient μu, the value of μu is one of the important indexes to evaluate seismic performance, it can be expressed by displacement ductility coefficient μu. The value of μu is larger, the ductility is better. Displacement ductility coefficient (μu) of specimens is shown in Table. 2. From Tab.2, it shows that arrangement type of lacing tubes has a great influence on displacement ductility of variable cross-sectional CFST laced column, the value order of μu as follow, K-type>flat>N-type >W-type. Meanwhile, the influence of longitudinal slope on variable cross-sectional CFST laced column is respectively small.

Table.2 Displacement ductility coefficient (μu) of Specimens

Speci-ments	BP-1	BK-1	BN-1	BW-1	BK-2	BN-2	BW-2
μ_u	4.12	4.39	3.47	2.38	4.06	3.78	2.24

5. Conclusions

Test results indicate that the hysteretic curves of specimen are relatively plump fusiform, it shows that variable cross-sectional CFST laced columns can absorb and dissipate seismic energy well and they have good seismic performance. Arrangement type of lacing tube and longitudinal slope has large influence to seismic behaviors of variable cross-sectional CFST laced columns. Compare with CFST laced column with flat lacing tube, elastic stiffness and horizontal peak load of CFST laced column with inclined lacing tube enlarge obviously, the value order of ductility as follow, K-type>flat>N-type >W-type. With the increase of longitudinal slope, the elastic stiffness and load carrying capacity increase gradually, and energy consumption improved consequently.

6. Acknowlegement

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