Experimental Study on the Hysteresis Performance of Stiffened Square CFST

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Abstract: Stiffened Square Concrete Filled Steel Tubular Columns (SSCFST) were proposed to solve the problem that ordinary square concrete-filled steel tubular columns (SCFST) are prone to appear local buckling and poor hysteresis performance before reaching the limits of carrying capacity in 3 cases such as the thin steel tubular wall, the larger diameter to thickness ratio or width to thickness ratio. In order to investigate its hysteresis behavior, based on introducing its basic concept, the manufacturing method was expounded, and the low cyclic loading tests of 15 SSCFST and 1 SCFST with binding bars were carried out. The author observed experimental phenomena, failure process and failure mode, then analyzed hysteresis loop area and energy dissipation of SSCFST columns under reciprocating loading, and discussed the effect of various factors to its anti-seismic behavior. Compared to SCFST with binding bars, SSCFST has superior anti-seismic performance.

1. Introduction
The constraint of ordinary SCFST columns on the inner filled concrete is mainly focused on the corner region, and the lateral constraint depends on the out-of-plane stiffness of the steel tubular wall(Han and Tao, 2001; Vrcelj and Uy, 2001) [1].

Scholars at home and abroad have conducted a series of studies on the improvement of axial compression behavior of CFST(Liang and Uy, 2000; Uy, 2000; Cai and He, 2006; Cai and He, 2007; Cai and Sun, 2008; Huang and Zhou, 2001; Tao and Han, 2005; Zhou et al., 2008; Susantha et al., 2001) [1-9].

2. Characteristics of SSCFST
The set of binding bars can greatly improve the mechanical properties of SCFST. Meanwhile, the elastic-plastic buckling phenomena will still appear in the area between the binding bars and as a result the constraints on inner filled concrete are undermined.
SSCFST proposed in this paper contain two enhanced measures that have been set with binding bars and stiffeners.

Fig.1(a)(b)(d)(e) show a typical elevations and cross-sections diagram of stiffened square concrete filled steel tube columns (SSCFST), in which (a) (b) are outer transverse and internal longitudinal type, (d) is outer transverse type, (e) is inner longitudinal type.

Fig.1(c) is SCFST with binding bars, Fig.1(f) is an ordinary SCFST.

![Diagram of specimens](image)

1- Anchoring end 2- Longitudinal stiffener 3- Horizontal stiffener 4-Binding bar 5-Concrete

**3. Making of specimens**

| No. | b (mm) | t (mm) | L (mm) | a (mm) | b (mm) | d (mm) | b_s*t_s (mm) | b_j*t_j (mm) | binding bars | n_0 |
|-----|--------|--------|--------|--------|--------|--------|--------------|--------------|--------------|-----|
| B2  | 200    | 6      | 600    | 100    | 100    | 10     | -            | -            | ordinary     | 0.6 |
| B6  | 200    | 6      | 600    | 100    | 100    | 10     | 40*6         | 40*6         | ordinary     | 0.4 |
| B7  | 200    | 5      | 600    | 100    | 100    | 10     | 40*5         | 40*5         | ordinary     | 0.4 |
| B8  | 200    | 4      | 600    | 100    | 100    | 10     | 40*4         | 40*4         | ordinary     | 0.4 |
| B9  | 200    | 6      | 600    | 100    | 100    | 10     | 40*6         | 40*6         | ordinary     | 0.6 |
| B10 | 200    | 5      | 600    | 100    | 100    | 10     | 40*5         | 40*5         | high strength| 0.6 |
| B11 | 200    | 4      | 600    | 100    | 100    | 8      | 40*4         | 40*4         | ordinary     | 0.6 |
| B12 | 200    | 6      | 600    | 100    | 100    | 10     | 40*6         | 40*6         | ordinary     | 0.8 |
| B13 | 200    | 5      | 600    | 100    | 100    | 10     | 40*5         | 40*5         | high strength| 0.8 |
| B14 | 200    | 4      | 600    | 100    | 100    | 8      | 40*4         | 40*4         | ordinary     | 0.8 |
| B15 | 200    | 6      | 600    | 100    | 85.7   | 10     | 40*6         | 40*6         | ordinary     | 0.6 |
In the table1, $B$, $t$, $L$ respectively represent the length of sectional side, the thickness of the pipe wall, and the length of the columns; $a$, $b$, $d$ respectively represent the horizontal spacing, the vertical spacing and the diameter of binding bar; $ih$, $iv$ respectively represent the thickness and the width of the built-in stiffeners; $oh$, $ov$ respectively represent the thickness and the width of the external stiffeners; $n_0$ represents the axial compression ratio.

The local buckling development of each specimen is shown in Table 2.

### Table 2: Hysteretic testing eigenvalues of specimens

| No. | occur of local buckling | 1 buckling wave length | 1 buckling wave length | 1 buckling wave length | buckling wave form a ring |
|-----|-------------------------|------------------------|------------------------|------------------------|---------------------------|
| B2  | 12r1 12r2               | 180mm                  | 12r3 190mm             | 20r1 190mm             | 20r2                      |
| B6  | 20r1 20r3               | 50mm                   | 30r1 60mm              | 30r3 60mm              |                           |
| B7  | 12r3 20r2               | 60mm                   | 20r3 70mm              | 30r2 70mm              |                           |
| B8  | 12r3 20r1               | 65mm                   | 20r2 75mm              | 30r2 75mm              |                           |
| B9  | 20r1 20r1               | 55mm                   | 20r2 75mm              | 40r1 65mm              |                           |
| B10 | 20r1 20r2               | 70mm                   | 20r3 80mm              | 40r1 75mm              |                           |
| B11 | 12r2 12r3               | 68mm                   | 20r1 80mm              | 30r1 80mm              |                           |
| B12 | 12r3 20r2               | 65mm                   | 20r2 75mm              | 30r1 75mm              |                           |
| B13 | 20r1 20r2               | 75mm                   | 20r3 80mm              | 30r2 80mm              |                           |
| B14 | 12r2 12r3               | 72mm                   | 20r1 75mm              | 20r2 85mm              |                           |
| B15 | 30r2 30r3               | 45mm                   | 40r1 50mm              | -                      |                           |
| B16 | 30r3 40r1               | 40mm                   | -                      | -                      |                           |
| B17 | 30r2 30r2               | 50mm                   | 40r1 55mm              | -                      |                           |
| C5  | 30r2 30r3               | 30mm                   | 30r3 30mm              | -                      |                           |
| C6  | 20r3 30r2               | 35mm                   | 30r3 35mm              | -                      |                           |
| C7  | 30r3 40r1               | 30mm                   | -                      | -                      |                           |

In the table, the digital in front of "r" is horizontal displacement (mm) under load; the digital in the back of "r" is the cycling number of the amplitude.

### Table 3: Area of hysteresis loops and energy dissipation coefficients of specimens

| No. | 3mm (1/200) | 6mm (1/100) | 9mm (1/67) | 12mm (1/50) | 20mm (1/30) | 30mm (1/20) | 40mm (1/15) |
|-----|-------------|-------------|------------|-------------|-------------|-------------|-------------|
| B2  | 1198.915    | 1869.226    | 3404.275   | 1478.850    | 2056.500    | 20118.336   | 23419.755   |
| B6  | 1584.555    | 1864.455    | 3334.235   | 1468.861    | 2089.906    | 23419.755   | 40376.120   |
| B7  | 1365.815    | 1863.761    | 3334.235   | 1468.861    | 2089.906    | 23419.755   | 40376.120   |
| B8  | 1347.735    | 1863.761    | 3334.235   | 1468.861    | 2089.906    | 23419.755   | 40376.120   |
| C5  | 2079.825    | 1908.728    | 3259.395   | 1703.950    | 2203.240    | 25839.190   | 40633.230   |
| C6  | 1819.090    | 1908.728    | 3259.395   | 1703.950    | 2203.240    | 25839.190   | 40633.230   |

In the table, the digital in front of "r" is horizontal displacement (mm) under load; the digital in the back of "r" is the cycling number of the amplitude.
4. Conclusion
Based on the hysteresis behavior test of 15 SSCFST and 1 SCFST with binding bars, the failure process and hysteresis loop area of SSCFST under reciprocating load are analyzed.

(1) The local buckling time is significantly delayed, the buckling wave length is obviously reduced, and the buckling modes emerged as a fundamental change. It shows the excellent anti-seismic resistance performance of SSCFST.

(2) The area of hysteresis loops and the energy dissipation coefficients of specimens with the thinner steel tubular wall still have good energy dissipation capacity. It shows SSCFST are considerably better than that of thick wall of SCFT specimen with binding bars specimens.

(3) The energy dissipation capacity of specimens can be improved with smaller ratio of width to thickness of the external stiffening plate or larger ratio of width to thickness of internal stiffening plate.

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In the table, area represents the area of the hysteresis loops; co. shows energy dissipation coefficients.
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