# Basic Experimental Study on Flexural Strength of Beam Web Connected to Circular CFT Column

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**SUMMARY:**
This paper is about the flexural strength of the beam web connected to circular concrete filled steel tubular column (from now referred to as CFT) when the out-of-plane deformation is considered. A simplified strength formula obtained by the mechanism method has been proposed. The purpose of this study is to discuss the effects of test parameters on the maximum strength. Test parameters are diameter-to-thickness ratio for CFT, presence or absence of scallops and presence or absence of in-filled concrete. In specimens with non-scallops, local buckling occurred and the loads decreased slowly. However, the loads of the specimens with scallops decreased suddenly after cracks occurred at the tip of scallop in the bottom flange. The deflections of specimens with non-scallops are larger than those with scallops. The maximum strength is larger, when there are non-scallops, the width-to-thickness ratio is smaller and there is in-filled concrete.

*Keywords: Beam-Column connection, Steel-Concrete Composite column, flexural strength*

## 1. INTRODUCTION

In the American Northridge earthquake and Hyogoken Nanbu earthquake, brittle failure occurred at the welding connections of the beam ends[1]. In addition, most brittle failures and cracks which observed near the full penetration welding connections of the through diaphragms and the beam flanges occurred at the lower flanges of the beams in the frame structures composed of square steel tubular columns with H-shaped beams[2].

To prevent such brittle failure, [The Guideline for Brittle Fracture Resistance at Welded Steel Beam Ends, 2nd Edition (in Japanese)] [1] (from now referred to as Guidance for Brittle Failure Prevention) was published in Japan. The design and welding construction methods of the connection of beam ends are shown, as well as the equations for evaluating the plastic rotational angle (i.e., the capacity of carrying deformation) of square steel tubular column with H-shaped steel beam.

About the connection of the CFT column and the H-shaped beam, the properties of the connection where the stress of beam flange is transmitted to the column through the diaphragm have been researched by many experimental studies. The strength evaluation method and the restoring force models' characteristics of the connection have been proposed. All of these have been summarized in Chapter4, Part 3 of Concrete-Filled Steel Tubular Structure Design and Construction Guidelines[3].

On the other hand, the flexural strength of the connection of the steel beam ends can be evaluated by the sum of the flexural strength of each beam flange and beam web. However, when the column is hollow steel column, the out-of-plane deformation occurs at the skin plate of column in which the beam web obsessed, and the bending moment of the beam web transferred to the column becomes smaller. As a result, the flexural strength of beam connection decreases. About the flexural strength of the connection of the square or circular hollow steel column and the beam web, the strength evaluation method has been proposed[4)-8)], so that depending on the width-to-thickness or the radius-to-thickness ratio of steel tube, the flexural strength of the connection of beam web can be evaluated. In addition, because of the out-of-plate deformation of steel tube, the load-transmission efficiency of the beam decreases and deformation capacity of the beam cannot be obtained [9]. The relation between the load-transmission efficiency and the capacity of deformation has been shown in several studies[10)-13)].

When the column is a square CFT, because of the presence of concrete, the out-of-plane deformation of the skin plate of the column can be restrained at the compressive portion of the beam web. However, at the tensile side, the out-of-plane deformation can hardly be restrained[14]. Therefore, the flexural strengths of the beam web connected to the square and circular CFT column have been calculated by the mechanism method. In addition, the experimental study about the connection of the square CFT column and H-shaped steel beam was carried out with the width-to-thickness ratio as the parameter[14),15)], and discussion about some analyses on the maximum strength and the distribution of strain at the beam has been presented[16]. However, there are no experimental studies focusing on the flexural strength of the connection of the beam web in the connection of the circular CFT column and H-shaped steel beam.

The purpose of this study is to carry out tests about the connection of the circular CFT and the H-shaped steel beam to make sure the effects of the diameter-to-thickness ratio of circular CFT columns, presence or absence of scallops and presence or absence of in-filled concrete with the maximum strength respectively. In addition, the loading conditions of the test are all the simple beam conditions and the both sides of the column are connected with beams. The portion of the column with the slab is subjected to compressive force. The both sides of slabs are subjected to compressive force. The loading condition of this test rarely occurs in the actual structure. This study is the basic one focusing on the out-of-plate deformation of the skin plate of the column and the flexural strength of connection of beam web.

## 2. TEST PROGRAM

### 2.1. Outline of test

Test specimens are all structures made of circular CFT columns and H-shaped steel beams. The size of the circular CFT column is $\phi\ 318.5 \times t_c$ ( $t_c$: the thickness of steel tubular column) , and that of the H-shaped steel beam is $\mathrm{H} - 400 \times 200 \times 8 \times 13$. Loading condition is simple beam form and monotonic loading. As mentioned in Chapter 1, the loading condition used in this test doesn't occur in the actual structure. This study is just a basic research that focuses on the out-of-plane deformation of the column and the flexural strength at the connection of beam webs, for this reason, this loading condition was adopted.

**Table 2.1** Test specimens

| Test specimens | C53C-NS | C53S-NS | C53C-S | C53C-NS |
|---|---|---|---|---|
| In-filled concrete | present | absent | present | present |
| Thickness of steel tubular column (mm) | 6 | 6 | 6 | 9 |
| diameter-to-thickness ratio of columns | 53(FC) | 53(FC) | 53(FC) | 35(FA) |
| Scallops | absent | absent | present | absent |
| Strength of in-filled concrete (N/mm$^2$) | 31.2 | - | 30.5 | 30.3 |

**Table 2.2** The actual dimension of a specimen (Unit: mm)

| Test specimens | C53C-NS | C53S-NS | C53C-S | C53C-NS |
|---|---|---|---|---|
| Thickness of beam flange | 12.93 | 12.94 | 12.94 | 12.91 |
| Thickness of beam web | 7.93 | 7.93 | 7.87 | 7.97 |
| Thickness of steel tubular column | 5.99 | 5.99 | 5.99 | 9.07 |
| Thickness of diaphragm | 19.21 | 19.33 | 19.21 | 19.23 |

Test parameters are the diameter-to-thickness ratio of columns, presence or absence of scallops and in-filled concrete. As shown in Table 2.1, the specimens are named as the different features of each parameter. The actual dimension of a specimen is shown in Table 2.2.

## 2.2. Test specimens

The shape of the specimen is shown in Figure 2.1. The material of steel tube column is the STK400 and beams' is the SN400B, and the diaphragm is the plate whose thickness is 19mm.

## 2.3. Material property

Tensile test is performed to investigate the material characteristics of steel. Tensile tests are carried out by using the test pieces of JIS No.1B which is cut out from H-shaped steel beam and diaphragm, respectively and by using test pieces of the JIS No.12C which is cut out from steel pipe. Table 2.3 shows the results of tensile test and Figure 2.2(a) shows the typical relation between the stress and the strain. The yield stress of steel column is obtained by 0.2% offset method.

The detailed information of the concrete is shown in Table 2.4. The cylinder compression test was carried out by three test pieces for each test specimen. The concrete compressive strength of each specimen is shown in Table 2.1. The example of stress-strain relation is shown in Figure 2.2(b)

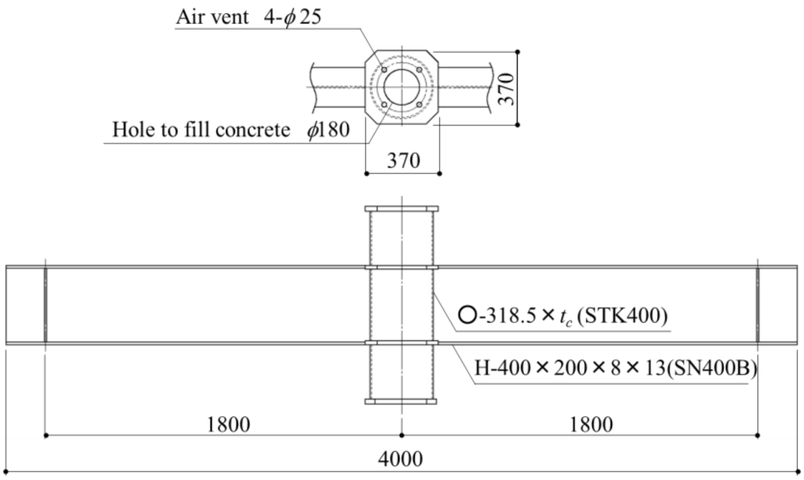
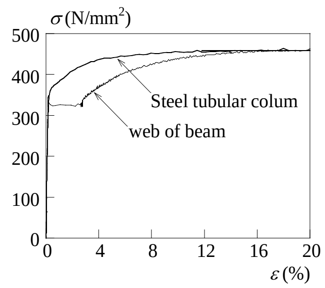
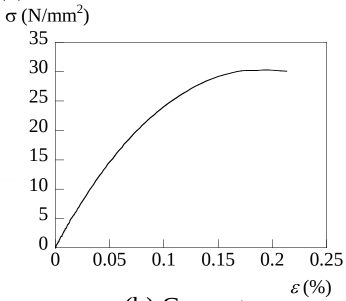



**Figure 2.1** The shape of the specimen




(a) Steel tubular column and beam web




(b) Concrete

**Figure 2.2 Stress-strain relations**

**Table 2.3** The results of tensile test

| Element | $\sigma_y$ (N/mm$^2$) | $\sigma_u$ (N/mm$^2$) | $\sigma_y/\sigma_u$ (%) | $\varepsilon_{st}$ (%) | *EL* (%) |
|---|---|---|---|---|---|
| Flange of beam | 295 | 445 | 66.4 | 2.27 | 29.57 |
| Web of beam | 327 | 463 | 70.7 | 2.86 | 29.2 |
| Steel tubular column (*t*=6mm) | 371 | 457 | 81.0 | - | 44.0 |
| Steel tubular column (*t*=9mm) | 346 | 463 | 74.8 | - | 48.8 |
| Diaphragm | 334 | 519 | 64.5 | 1.38 | 25.2 |

$\sigma_y$ , $\sigma_u$ :yield stress and tensile strength, $\sigma_y/\sigma_u$: yield ratio
$\varepsilon_{st}$ , *EL* : strain at the begin of strain hardening and elongation at breaking

**Table 2.4** The detailed information of the concrete

| Element | Water-cement ratio (%) | cement (kg/m$^3$) | water (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Admixture (kg/m$^3$) | Slump (cm) |
|---|---|---|---|---|---|---|---|
| Infilled Concrete | 45.0 | 414 | 486 | 742 | 971 | 3.73 | 18 |

### 2.4 Loading and measuring method

Loading apparatus and the method of measurement are shown in Figure 2.3. The vertical displacements of two points at one end of the beams ($v_1$,$v_2$) and a point at the other end of the beam ($v_3$) are measured (shown as Figure 2.3). The vertical displacements at left and right ends of the beam ($\delta_s$ and $\delta_n$) are calculated by Eq. 2.1 and Eq. 2.2 respectively.

$$\delta_s = \frac{v_1 + v_2}{2} \tag{2.1}$$

$$\delta_n = v_3 + \frac{v_2 - v_1}{2} \tag{2.2}$$

The column is the rigid body with diaphragm and rotated an angle $\theta_c$ around the loading point. The rotational angle $\theta_c$ can be calculated by Eq. 2.3.

$$\theta_c = \sin^{-1}\left(\frac{\delta_s - \delta_n}{D}\right) \tag{2.3}$$

The rotational angles at left and right sides of the beam ($\theta_n$ and $\theta_c$) can be calculated by Eq. 2.4 and Eq. 2.5. In which, $l_n$ and $l_s$ are the length from the joints to the surface of the column and the subscripts *n* and *s* represent the left and right sides respectively.

$$\theta_n = \theta_n' + \theta_c = \tan^{-1}\frac{\delta_n}{l_n - D/2} + \theta_c \tag{2.4}$$

$$\theta_s = \theta_s' - \theta_c = \tan^{-1}\frac{\delta_s}{l_s - D/2} - \theta_c \tag{2.5}$$

## 3. TEST RESULTS

Load *P*- rotational angle $\theta$ relations are shown in Figure 3.1. Figure 3.1 (a) ~ (c) show the comparisons between the standard test body, C53C-NS, and the other specimens which have differences in the diameter-thickness ratio, presence or absence of scallop and presence or absence of in-filled concrete

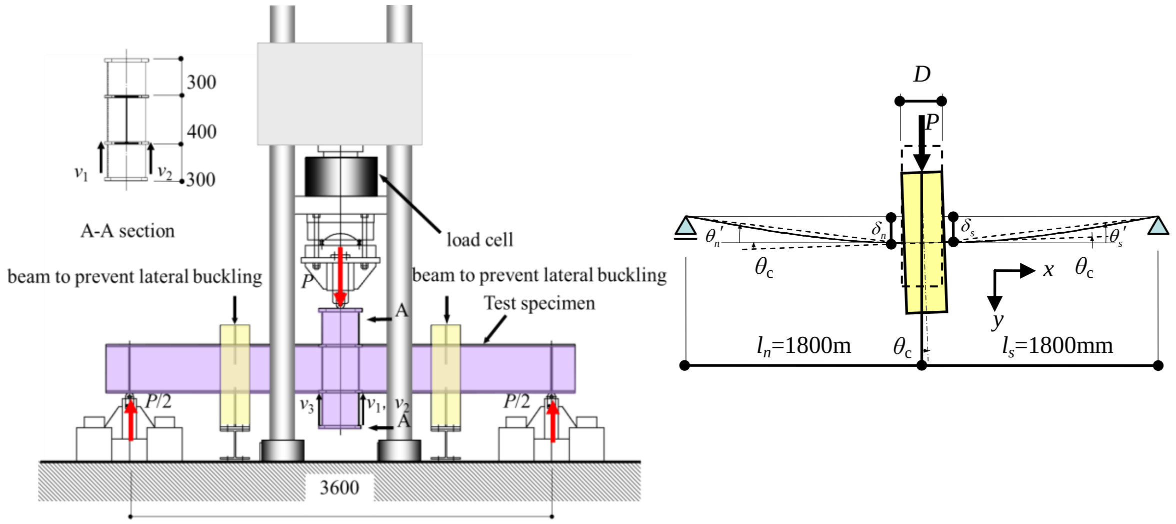
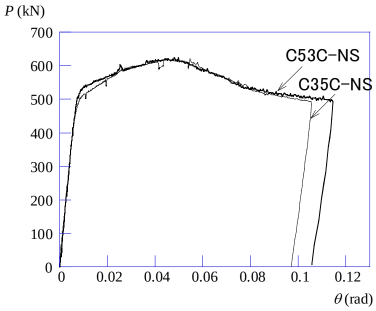
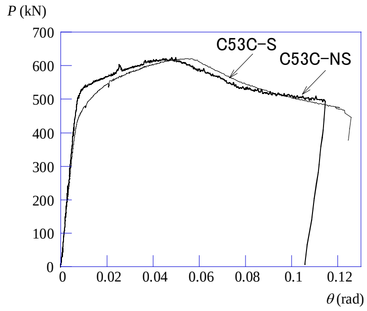


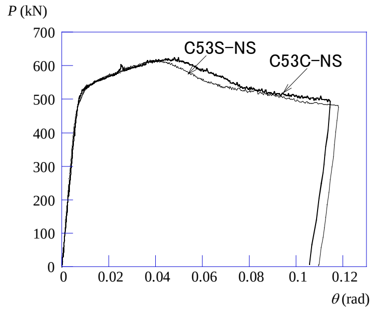

**Figure 2.3 Loading apparatus and the method of measurement**




(a)Comparison of the difference of diameter-thickness ratio




(b) Comparison of scallop with non-scallop




(c) Comparison of CFT column with hollow steel tube column

**Figure 3.1 Load *P*-slope angle $\theta$**

**Table 3.1** The corresponding rotational angle and the maximum load

| Test specimen | C53C-NS | C53S-NS | C53C-S | C53C-NS |
|---|---|---|---|---|
| Maximum load (kN) | 624 | 617 | 621 | 622 |
| Corresponding rotational angle (rad) | 0.0498 | 0.0414 | 0.0543 | 0.0449 |

respectively. The maximum load and corresponding rotational angle and the maximum load are shown in Table 3.1.

In all the test specimens, local buckling occurred at the top beam flanges, and after maximum strength, load decreased slowly. The crack did not arise.

The influence of each parameter is considered on maximum load. According to Figure 3.1 and Table 3.1, the influence of each parameter on maximum loading is not remarkable. About the differences of the diameter-thickness ratios, according to Figure 3.1 (a) and Table 3.1, the maximum load is almost the same. About the presence or absence of scallop, according to Figure 3.1 (b) and Table 3.1, the maximum load of specimen with scallop is slightly larger. Also the rotational angle is larger on maximum load. About the presence or absence of in-filled concrete, according to Figure 3.1(c) and Table 3.1, the load of the hollow specimen without filled concrete is larger than the load of the specimen in-filled concrete. On maximum load the rotational angle of the CFT specimen is larger.

## 4. CONCLUSIONS

To make sure the effects of the diameter-to-thickness ratio for CFT, presence or absence of scallops and presence or absence of in-filled concrete with the maximum strength respectively, the test about the connection of the circular CFT and the H-shaped steel beam has been performed. The loading conditions of the test are the simple been conditions. The influence of each parameter on maximum strength is not remarkable. The specimen with scallop and the specimen with column are larger than others.

This study focuses on the out-of-plan deformation of the skin plate steel of the column and the flexural strength of connection of beam web. Because the loading condition of the test is not the real condition, we will take more tests under different loading conditions in the future.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