

# EXPERIMENTAL STUDY ON SEISMIC BEHAVIOR OF CONCRETE FILLED TUBE BASE CONNECTIONS

# Hsieh-Lung HSU<sup>1</sup> and Huan-Wen LIN<sup>2</sup>

# SUMMARY

This study is focused on the experimental investigation of relationship between design details and column base performance, such as strength and rigidity. Results from specimens tested under combined axial and lateral loads were used to define the effectiveness of the base connections. It was observed from test comparisons that the rigidities of base connections increased when the embedded depths increased. It was also found that the base connections possessed higher stiffness and energy dissipating capability when stiffeners were added to the base connections. Finally, an empirical expression for base rigidity estimation is proposed for design purposes.

# INTRODUCTION

Concrete-filled tubes (CFT) are effective structural forms for earthquake-resistant purposes because of their high compressive strength and ductility. Significant seismic performance of such designs can be guaranteed only when adequate design details are employed. In order to establish adequate design guidelines, responses of CFT members under axial load, bending or their combinations must be defined. For these purposes, a number of studies on the CFT member behavior have been conducted [1-5]. These studies are mostly focused on the member behavior, however, information on the influence of CFT base connection rigidity to the structural performance are still limited. It has been indicated in the investigation report of 1995 Hyogoken-Nanbu earthquake [6] that many structural damages are directly related to the failure of foundations. Therefore, adequate recommendations to the base connection designs so that the connection can possess sufficient strength and rigidity to prevent premature failure is essential to the seismic design of CFT structures.

In general, base connections of composite members can be designed in exposed and embedded forms, as shown in Figure 1. Fabrications of exposed base connections are easier than those of embedded types, however, the formers are less reliable because the connection rigidities solely rely on the effectiveness of the preset anchor bolts. Unless large number of anchor bolts and extremely thick end plates are employed, which should be avoided when construction costs are concerned, the base rigidities during earthquakes are susceptible.

<sup>&</sup>lt;sup>1</sup> Professor, Dept. of Civil Engineering, National Central University, Chung-Li, Taiwan 32054

<sup>&</sup>lt;sup>2</sup> M.S., formerly Graduate student, Dept. of Civil Engineering, National Central University, Chung-Li, Taiwan 32054



Figure 1 Fabrication of Base Connections

For embedded base connections, connection rigidities can be improved by the additional resistance of concrete within the embedded depth. In such type of construction, concrete fabrication needs to be completed in two pouring, which incurs discontinuous interface and complicated load transmission mechanism among anchor bolts, embedded CFT segment and confining concrete. In order to sustain sufficient foundation stiffness and strength so that ductility of CFT members can be fully developed, this load transmission mechanism must be adequately investigated and defined.

This study is focused on the experimental investigation of relationship between design details and column base performance, such as strength and rigidity. Results from specimens tested under combined axial and lateral loads were used to define the effectiveness of the base connections and to establish the references for design purposes.

# **EXPERIMENTAL PROGRAM**

#### Specimens

Seven square CFT members with various lengths (05D, 1.0D and 1.5D; D=section depth) embedded to corresponding foundations were fabricated for testing. Tube dimensions for all members (width x depth x thickness) were 350x350x7 mm, which resulted in width/thickness ratio of 50. Yield strength of the steel tube was 324 MPa. Each steel tube was fillet-welded to a 32 mm-thick end plate before concrete casting. Foundation concrete was cast in two pouring: one for anchor bolt mounting and the other to complete the foundation and CFT member filling. Concrete strengths determined from the cylinder tests for the first and second pouring were 24.3 and 35.4 MPa, respectively. Four ASTM A325 M27 anchor bolts were used to erect the CFT member in each foundation. In order to investigate the possibility of improving foundation rigidity, the steel tubes of three specimens were stiffened within the embedded segments. This concern was conducted to investigate whether failure surface could be moved from the highly-stressed CFT embedded area to the foundation surface so that the integrity of foundation could be sustained and the performance of CFT members could be fully developed. Specimen details are shown in Figure 2. Table 1 also lists the compositions of the specimens.



**Figure 2 Specimen Details** 

Table	1	Sp	becimen	Com	positions
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Specimen	Embedded depth (De)	Stiffener	Anchor bolt	α			
U-05	0.5D	No	Yes	2.13			
U-10	1.0D	No	Yes	2.58			
U-15	1.5D	No	Yes	2.80			
S-00	0	Yes	Yes	1.08			
S-05	0.5D	Yes	Yes	2.41			
S-10	1.0D	Yes	Yes	2.79			
S-15	1.5D	Yes	Yes	2.92			
D = depth of CFT = 350 mm							

#### **Test apparatus**

Each foundation was mounted on the strong floor with four high strength rods. In order to establish the relationship between base rigidities and the corresponding fabrication details, specimen were first subjected to only lateral load within the elastic range to obtain the members' elastic stiffness. After unloading, the specimens were then tested under combined constant axial and cyclic lateral load. Two sets of loading apparatus were used to generate the required loads. The lateral load was generated by a servo-controlled hydraulic actuator through a series of prescribed cyclic displacements, as shown in Figure 3, and the constant axial load was generated by a hydraulic jack pushing against a stiffened reaction beam. Test setup is shown in Figure 4. The magnitude of axial load was set to 15% of the member's compressive strength ( $P_{o}$ ), which could be calculated as following:

$$P_o = A_s F_{vs} + A_c f_c' \tag{1}$$

in which,  $A_s$  and  $A_c$  were the cross-sectional areas of the steel tube and the in-filled concrete, and  $F_{ys}$  and  $f_c$ ' were the yield strength of tube and compressive strength of concrete, respectively. Strain gages mounted on the anchor bolts and the CFT tubes were used to measure the specimen responses.



### Observations

Figure 5 shows some typical hysteretic relationships for specimens with various base compositions. It can be observed from the figure that whenever the base connections possess sufficient strength, the CFT members are capable of developing their full bearing capacity, such as U-10 and U-15 specimens. However, for specimen with inadequate base design details, for example insufficient embedded segment as in U-05 specimen, premature cracking in the base concrete occurred before CFT member reached its moment capacity. Failure patterns for specimens with various base compositions are shown in Figures 6 and 7.



Figure 5 Typical Hysteretic Relationships: (a) S-00; (b) U-05; (c) U-10; (d) U-15





(a)





(b)





Figure 6 Failure Patterns for Unstiffened Base Connections: (a) U-05; (b) U-10; (c) U-15





(a)





(b)





(c)



(d)

Figure 7 Failure Patterns for Stiffened Base Connections: (a) S-00; (b) S-05; (c)S-10; (d) S-15

#### **COMPARISONS OF TEST RESULTS**

#### **Base rigidity**

In order to accurately predict the structural responses, the member stiffness as well as the foundation's boundary conditions must be adequately defined. For a cantilever beam with perfectly rigid boundary, the member's flexural stiffness (K) can be calculated as following:

$$K=3EI/L^3 \tag{2}$$

However, the theoretical rigid boundary does rarely exist in a real structure. Therefore, a reasonable estimation on the boundary rigidity with specified fabrication details is more feasible and essential for structural designs. This concern is particularly critical for the design of CFT structures, because the structures usually possess higher strength and stiffness than steel or reinforced concrete structures with similar member dimensions. In such cases, influence due to discrepancy in base rigidity estimation will become significant and the analytical results are also biased.

Assuming that the flexural stiffness of specimens with various fabrication details are in the following form:

$$K = \alpha E I / L^3 \tag{3}$$

in which,  $\alpha$  is a coefficient related to the various foundation placements. The values of  $\alpha$  for the specimens are calculated using information obtained from bending tests, and are listed in Table 1 and compared in Figure 8.



Figure 8 Comparisons of Base Rigidities

As indicated in previous section that the failures of base connections are usually governed by the length of embedded segment. Once the embedded depth of member is larger than the critical value, the CFT member usually fails prior to the foundation. However, it can be observed from Figure 8 that the base rigidities varied even though the specimens possessed sufficient strength and similar failure patterns. In general, the base rigidities increased with the increasing of embedded length, however, the increments were in different rates for stiffened and unstiffened bases. They were:

(For U-series) 
$$\alpha = -0.4763 D^2 + 1.627 D + 1.4313$$
 (4)

(For S-series) 
$$\alpha = -0.4878 D^2 + 1.4888 D + 1.7882$$
 (5)

It is interesting to find that when the embedded length reached an extreme value, 1.5D, which is too costly in construction projects, the achievable member stiffness is still less than the theoretical  $3EI/L^3$ , therefore, the above expressions can serve as more feasible design references for design purposes.

#### Load transmission mechanism

For CFT bases with embedded segments and anchor bolts, the connection strength can be calculated by summing the component strengths of anchor bolts and confining concrete. Figure 9 shows the comparisons of the moments resisted by the anchor bolts  $(M_{bolt})$  and the whole base connection  $(M_{base})$ . Loading induced on the anchor bolts was calculated by the installed strain measurements. It can be found from the figure that for CFT base connection with less embedded segment, strength requirement for the anchor bolts became extremely critical. For example, the anchor bolts of a U-05 specimen were required to provide 33 % of the base connection's moment resisting capacity. This induced heavy stress concentration and increased the possibility of concrete fracturing on the bolt locations. However, when pairs of stiffeners were added to the embedded CFT segment of base connection with details same as U-05, i.e. S-05, the strength requirement for the anchor bolts was significantly reduced, approximately to 2/3 of that of U-05. These phenomena, in conjunction with the achievable base rigidities described in previous sections, explained the effectiveness of the stiffening scheme to the improvement of base connection performance.



Figure 9 Comparisons of Moment Resisting Ratios

### **Energy dissipation**

Figure 10 shows the comparisons of energy dissipation for the tested specimens. It can be found that the exposed-type base connection, i.e. S-00 mounted with anchor bolts only, exhibited poor performance due to inadequate energy dissipation mechanism. An improved, however still insufficient, energy dissipating performance was achieved in specimen U-05 when CFT member was embedded to the foundation. The energy dissipation capability continued to increase when the embedded depth increased. This phenomenon stabilized when the embedded depth reached a critical value, approximately 1.0D. The comparisons also showed that the energy dissipation of stiffened base connection was higher than that of unstiffened one with same embedded depth, which further validated the applicability of the stiffening scheme.



#### CONCLUSIONS

This study focused on the experimental investigation of relationship between design details and column base performance. Test results showed that the rigidities of base connections increased when the embedded depths increased. It was also found that the base connections possessed higher stiffness and energy dissipation capability when stiffeners were added to the embedded segment. Finally, an empirical expression for base rigidity estimation is proposed for design purposes.

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#### REFERENCES

- 1. Boyd PF, Cofer WF, Mclean DI. "Seismic performance of steel-encased concrete columns under flexural loading." ACI Structural Journal 1995; 92(3): 355-364.
- 2. Kallolil JJ, Chakrabarti SK. "Experimental investigation of embedded steel plates in reinforced concrete structures." Engineering Structure 1998; 20(1-2): 105-112.

- 3. Ninakawa T, Sakino K. "Inelastic behavior of concrete filled circular steel tubular columns subjected to uniform cyclic bending moment". Proc. 11th World Confer. Earthquake Eng., Acapulco, Mexico, No.1385, 1996.
- 4. Pertold J, Xiao RY, Wald F. "Embedded steel column bases I. experiments and numerical simulation." J. Construct. Steel Res. 2000; 56: 253-257.
- 5. Usami T, Ge H. "Ductility of concrete-filled steel box columns under cyclic loading." Journal of Structural Engineering 1994; 120(7):.2021-2040.
- 6. Atorod A, Ghosh SK. "Steel reinforced concrete structures in 1995 Hygoken-nanbu earthquake", Journal of Structural Engineering 1997; 123(8): 986-992.