Engineering Structures 33 (2011) 1479–1490

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

# Nonlinear finite element analysis of CFT-to-bracing connections subjected to axial compressive forces

Hsuan-Teh Hu [a,*], Chun-Wei Chen [b], Mei-Yun Huang [b]

[a] Department of Civil Engineering and Sustainable Environment Research Center, National Cheng Kung University, Tainan, Taiwan, ROC

[b] Department of Civil Engineering, National Cheng Kung University, Tainan, Taiwan, ROC

ARTICLE INFO

*Article history:*
Received 17 January 2009
Received in revised form
27 January 2010
Accepted 21 January 2011
Available online 26 February 2011

*Keywords:*
Concrete-filled tube
Bracing
Axial force
Finite element analysis

ABSTRACT

The Abaqus finite element program together with nonlinear material constitutive models for concrete-filled tube (CFT) and steel gusset plate is used to analyze the behaviors of the gusset plate type CFT-to-Bracing connections subjected to axial compressive forces. It is found that the failure of CFT-to-Bracing connections occurs below the connecting area. Local bulged shapes of the steel tube might take place in the areas close to the gusset plate and the fixed end under the failure stage. The ultimate strengths of the CFT columns slightly increase with the increasing of the load ratio and the thickness of the gusset plate. The introduction of the cutouts on the gusset plates slightly increases the ultimate strength of the CFT column and causes more local bulged shapes on the steel tubes below the connection area under the failure stage.



## 1. Introduction

A concrete-filled tube (CFT) column consists of a steel tube filled with concrete. Due to the benefit of composite action of both materials, the CFT columns provide excellent seismic resistant structural properties such as high strength, high ductility and large energy absorption capacity. Therefore, CFT columns have gained popularity in supporting heavy loads in high-rise buildings, bridges and offshore structures. Various experimental and analytical studies have been performed on CFT columns [1–17] and special interests have been focused on the connection regions [18–24].

The aim of this investigation is to employ the nonlinear finite element program Abaqus [25] to perform numerical simulations of the gusset plate type CFT-to-bracing connections (Fig. 1) subjected to axial compressive forces $P_a$ and $P_g$. To achieve this goal, proper material constitutive models for steel gusset plate, steel tube and concrete core are proposed. Then the proposed material constitutive models are verified against experimental data of Yang [26]. Finally, the influence of the thickness of the gusset plate, the cutouts on the gusset plate and the type of loading on the behavior of CFT-to-Bracing connections are studied and discussed.

* Corresponding author. Tel.: +886 6 2757575x63168; fax: +886 6 2358542.
*E-mail address:* hthu@mail.ncku.edu.tw (H.-T. Hu).

0141-0296/$ – see front matter 
doi:10.1016/j.engstruct.2011.01.018

## 2. Material properties and constitutive models

The experiment for CFT-to-bracing connections subjected to axial compressive forces (Fig. 1) was carried out by Yang [26]. There are seventeen specimens in total (Table 1). These CFT columns are subjected to compressive forces $P_a$ and $P_g$ to the end of the columns and the gusset plates, respectively. The tested specimens can be categorized into three groups. The first group of the CFT column contains the S specimen which has no gusset plate at all. The S specimen is subjected to axial compressive force $P_a$ to the end only. The second group of the CFT columns contains the P specimens. The first number after P is the thickness of the gusset plate (in mm), which could be 12, 24 and 36. The second number after P is the load ratio $P_a/(P_a + P_g)$ in terms of percentage. For example, P24-67 specimen stands for CFT column having a gusset plate with 24 mm thickness and a load ratio $P_a/(P_a + P_g) = 67\%$. The third group of the CFT columns contains the PH specimens. Same as the P specimens, the first number after PH is the thickness of the gusset plate and the second number after PH is the load ratio. However, the gusset plates of the PH specimens contain circular cutouts. The 24 mm gusset plate has 2 circular holes and the 36 mm gusset plate has 3 circular holes. The dimensions and positions of these holes on the gusset plates are shown in Fig. 2. From Table 1, we can observe that the length H of the S specimen is equal to 795 mm. The length of the rest P and PH specimens is equal to 1590 mm. The diameter $D$ and the thickness $t$ of all the tubes are equal to 265 mm and 7 mm, respectively.

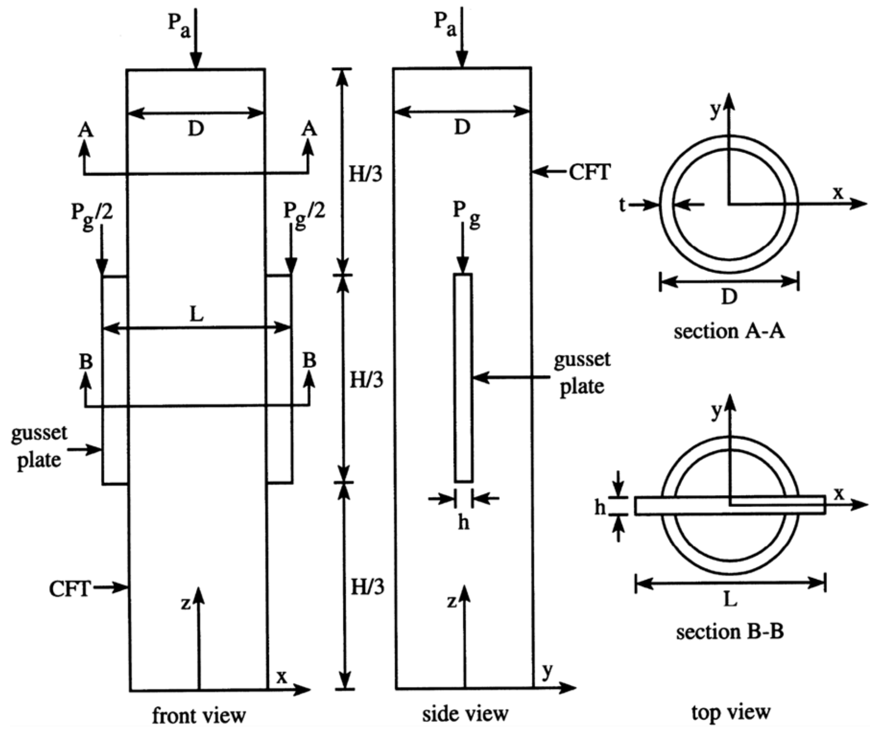


**Fig. 1.** Geometry and loading of gusset plate type CFT-to-Bracing connection.

**Table 1**
Dimensions and load ratios of CFT columns.

| Specimen | $H$ (mm) | $D$ (mm) | $L$ (mm) | $t$ (mm) | $h$ (mm) | $D/t$ | Numbers of holes on gusset plate | Load ratio $P_a/(P_a+P_g)$ (%) |
|---|---|---|---|---|---|---|---|---|
| S | 795 | 265 | 320 | 7 | – | 37.86 | 0 | 100 |
| P12-00 | 1590 | 265 | 320 | 7 | 12 | 37.86 | 0 | 0 |
| P12-33 | 1590 | 265 | 320 | 7 | 12 | 37.86 | 0 | 33 |
| P12-67 | 1590 | 265 | 320 | 7 | 12 | 37.86 | 0 | 67 |
| P24-00 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 0 | 0 |
| P24-33 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 0 | 33 |
| P24-67 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 0 | 67 |
| P24-100 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 0 | 100 |
| P36-00 | 1590 | 265 | 320 | 7 | 36 | 37.86 | 0 | 0 |
| P36-33 | 1590 | 265 | 320 | 7 | 36 | 37.86 | 0 | 33 |
| P36-67 | 1590 | 265 | 320 | 7 | 36 | 37.86 | 0 | 67 |
| PH24-00 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 2 | 0 |
| PH24-33 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 2 | 33 |
| PH24-67 | 1590 | 265 | 320 | 7 | 24 | 37.86 | 2 | 67 |
| PH36-00 | 1590 | 265 | 320 | 7 | 36 | 37.86 | 3 | 0 |
| PH36-33 | 1590 | 265 | 320 | 7 | 36 | 37.86 | 3 | 33 |
| PH36-67 | 1590 | 265 | 320 | 7 | 36 | 37.86 | 3 | 67 |

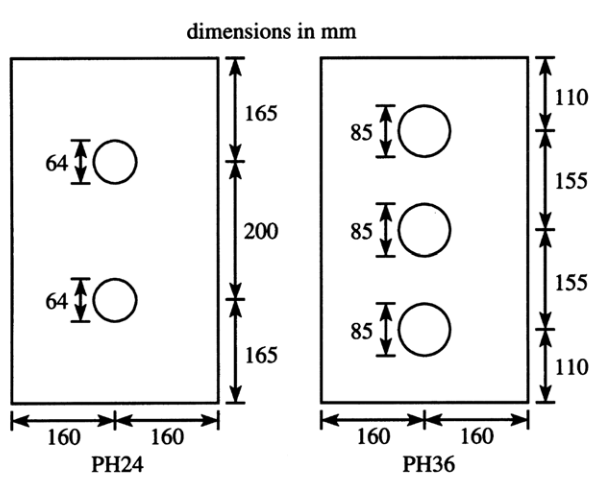


**Fig. 2.** Cutouts on the gusset plates.

### *2.1. Steel tube and steel gusset plate*

In the analysis, Poisson's ratio $\nu_s$ and the elastic modulus $E_s$ of the steel tube and steel gusset plate are assumed to be 0.3 and 200 GPa, respectively. The uniaxial behavior of the steel tube and the steel gusset plate is modeled by a piecewise linear model and their stress–strain curves used in the analysis are shown in Fig. 3.

When the steel tube and the steel gusset plate are subjected to multiple stresses, a von Mises yield criterion is employed to define the initial yield surface, which is written as

$$F = \sqrt{3J_2} - \sigma_y = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2} - \sigma_y = 0 \quad (1)$$

where $J_2$ is the second stress invariant of the stress deviator tensor and $\sigma_1$, $\sigma_2$, and $\sigma_3$ are the principal stresses. Fig. 4 shows the von Mises yield surface in the three-dimensional principal stress space. The response of the steel tube and the steel gusset plate