Engineering Structures xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Engineering Structures

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

Comprehensive stress-strain model of square steel tube stub columns under compression

Hua Zhao [a,c], Yuping Sun [b,*], Takashi Takeuchi [b], Shichun Zhao [a]

[a] School of Civil Engineering, Southwest Jiaotong University, Chengdu 611756, China
[b] Department of Architecture, Graduate School of Engineering, Kobe University, Kobe 657-8501, Japan
[c] Department of Civil Engineering, Technology University of Chengdu, Chengdu 578501, China

ARTICLE INFO

Article history:
Received 4 November 2015
Revised 15 October 2016
Accepted 18 October 2016
Available online xxxx

Keywords:
Square steel tube
Stub column
Steel plate
Yield strength
Local buckling
Buckling strength
Buckling strain
Generalized width-to-thickness ratio

ABSTRACT

A stress-strain model is proposed to define the relationship between axial compressive stress and strain for square steel tube stub columns, which have been widely used as predominant gravity-sustaining structural components in high-rise buildings and skyscrapers. The proposed model consists of two equations, defining the ascending branch and descending branch of the stress-strain curve, respectively, and has a significant advantage over previous models in that it can trace effects of both the residual stress induced during manufacturing process and the local buckling of steel plate on the compressive stress-strain behavior of square steel tube stub columns. Another feature of the proposed model is that it can be used to the stub columns made of very thin steel plates. In order to calibrate the new stress-strain model and verify its reliability and accuracy, sixty-eight hollow square steel tube stub columns under monotonic axial compression are collected. The previous tests cover a wide range of structural factors such as yield strength and width-to-thickness ratio of steel plates. In particular, the previous tests include stub columns made of steel plate with high yield strength of up to 835 MPa. Comparisons between the experimental results and the calculated ones indicate that the proposed model cannot only predict the local buckling strength and the corresponding strain very well, but also trace the compressive stress-strain behavior of square steel tube stub columns up to large strain with high accuracy.

1. Introduction

Due to high strength and reliable ductility of steels, square steel tube (SST) has been widely used in the form of hollow or concrete-filled steel tube (CFT) stub column as the gravity-sustaining component in modern high-rise buildings constructed not only in aseismic regions but also in earthquake-prone zones such as Japan. The Kobe earthquake (1995, Japan) has proved that steel structures made of SST stub columns, hollow and concrete-filled, can survive strong design-earthquake and achieve the goal to protect buildings from collapse without severe damages.

Seismic capacity of steel structures depends largely upon the strength and ductility of steel columns. It is well known that in order for steel columns to fully develop their yield strength and ductility, it is necessary to prevent them from premature buckling under compressive stresses induced by gravity and/or bending moment before the steel plates reach their yield strengths. For a SST stub column in high-rise steel building structures, local buckling, which is caused by too large width-to-thickness (B/t) ratio of the plates that form the steel tube, is much more critical than overall buckling because the slenderness ratio of the stub column is generally small enough. Consequently, prevention of local buckling has been one of the key points in seismic design of SST stub columns.

Conventionally, limiting B/t ratio of steel plates has been a standard method to prevent SST stub columns from local buckling. In the current design codes and standards for steel structures [1–4], there are generally two limiting values imposed on the B/t ratio of steel plates. One is intended to ensure that SST stub columns have sufficient ductility before inelastic local buckling occurs, and the other is to prevent the steel plates from elastic local buckling so that the stub columns can develop their yield moment resistance. None of the current design codes, however, deals with the post-local-buckling behavior of SST stub columns, while the knowledge of it is of great importance from the viewpoint of accurately assessing seismic performance of steel structures subjected to very strong earthquakes.

* Corresponding author at: Department of Architecture, Graduate School of Engineering, Kobe University, 1E-206, 1-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan.

E-mail address: sun@person.kobe-u.ac.jp (Y. Sun).

http://dx.doi.org/10.1016/j.engstruct.2016.10.036
0141-0296/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Zhao H et al. Comprehensive stress-strain model of square steel tube stub columns under compression. Eng Struct (2016), http://dx.doi.org/10.1016/j.engstruct.2016.10.036

The importance to understand the post-local-buckling behavior of SST stub columns and its effect on overall seismic performance of steel structures has recently gained increasing attention in Japan. In 2011, Japanese government officially released that the probability of occurrence within the coming 30 years of a stronger earthquake than anticipated in current design code was assessed as high as 60–70% [5]. This earthquake has been named as Nankai-trough earthquake whose epicentre is close to the Kansai area of Japan, and estimated to have a moment magnitude of up to 9.0. Because soft subsoil distributes widely in the Kansai area, the Nankai-trough earthquake might cause long-period strong ground motion and make the high-rise steel structures there to resonantly sway beyond the drift limit anticipated under the current design-strong earthquake. It is the coming Nankai-trough earthquake that necessitates urgent investigation of the post-local-buckling behavior of steel columns under compression to better understand the ultimate failure mechanism that high-rise steel buildings might exhibit when hit by a stronger earthquake than expected.

Many researchers have experimentally and analytically investigated the stress-strain behavior of SST stub and slender columns under compression [6–25], but most of the previous studies emphasized the evaluation of local buckling strength and corresponding strain. The primary researches on the post-local-buckling behavior of SST stub columns are those conducted by Yamada et al. [11,15] and Sakino et al. [18]. Based on the test results of dozens of SST stub columns under axial compression, Yamada et al. have proposed a compressive stress-strain model for hollow SST stub columns in form of a multi-linear function [11,Yamada model]. Sakino et al. have developed a similar multi-linear model [18,Sakino model] for the SST in square CFT stub columns. While both models have been proposed for the cold-formed SSTs, which have been prevalently used in Japan, accuracy of these models have not been verified even in the referenced papers [11,15,18].

Fig. 1 shows outlines of the two models along with comparisons with the experimental stress-strain curves of three representative hollow SST stub columns tested by Fujimoto et al. [19]. The ordinate in Fig. 1 expresses the compressive axial stress normalized by the yield strength (f_{sy}) of steel plates. The term α shown in Fig. 1 is the so-called generalized width-to-thickness ratio of steel plates and has been conventionally used as a key factor measuring the thickness of steel plates for SST instead of the B/t ratio in Japan. Definition of α will be given later.

Several observations can be made from Fig. 1 about the compressive stress-strain behavior of the cold-formed SST stub columns as well as the accuracy of previous models. (1) The compressive stress-strain curve exhibits strong nonlinearity before reaching the yield strength of steel plates due to the residual stress induced during manufacturing process; (2) the thinner the steel plate, the smaller the stress and strain where local buckling commences; (3) Yamada model can trace stress-strain behavior well for the SST stub columns made of thin steel plates having large α value, but tends to overestimate experimental result of the SST stub columns with small α value; and (4) Sakino model, originally proposed for the SST in square CFT stub columns, cannot be utilized to predict compressive stress-strain behavior of hollow SST stub columns.

From the above-mentioned observations one can see that previous models may overestimate seismic capacities of hollow SST and square CFT stub columns subjected to very strong earthquakes [15,26]. Therefore, in order to conduct reliable analysis of seismic performance of steel structures made of SST stub columns, a new compressive stress-strain model is desirable. The new model should, (1) be able to trace the post-local-buckling behavior up to large strain with higher reliability and accuracy than previous models, (2) widen its application to square steel tubes with larger α value, and (3) be as concise as possible to make the model design or analysis-oriented.

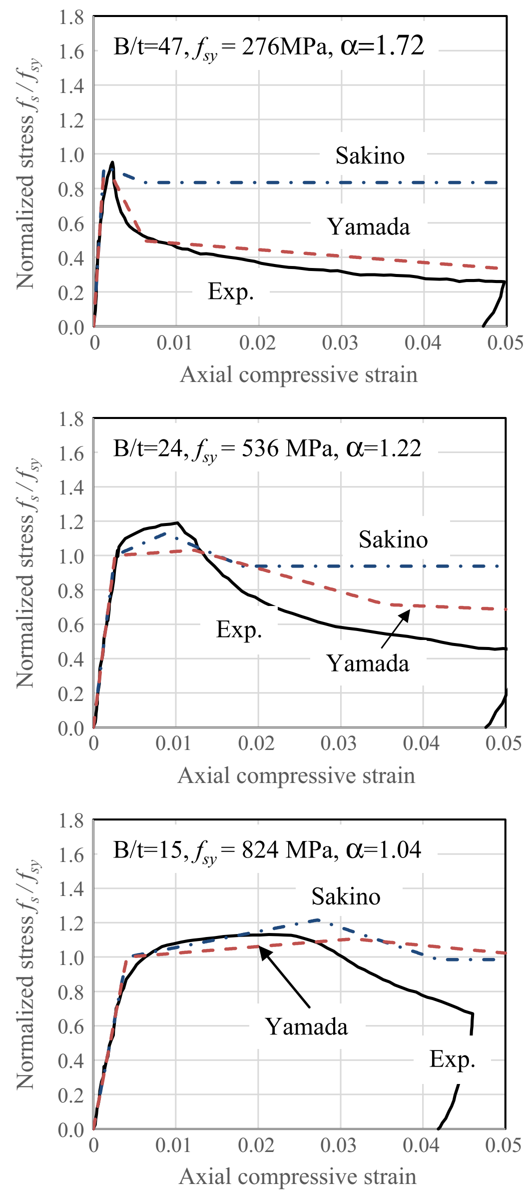

Fig. 1. Outline of previous models and comparison with experimental results [19].

The objective of this paper is to propose a new stress-strain model for SST stub columns under compression. To reduce potential calculation errors caused around turning points in the previous multi-linear models, the new model consists of two curves. One curve is adopted for the ascending portion to trace the effect of the residual stress induced during manufacturing process of SSTs, and the other is adopted to trace the post-local-buckling behavior as accurately as possible.

2. Description of the previous experimental data

Experimental results of sixty-eight SST stub columns under concentric compression are collected to calibrate the proposed model. Table 1 shows main experimental variables in the test columns as well as their varying ranges. Fig. 2 shows the relationships