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Prediction of axial load capacity of stub circular concrete-filled steel tube using fuzzy logic

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ABSTRACT

A circular concrete-filled steel tube (CFST) has several advantages compared with the conventional reinforced concrete member or hollow steel tube, since the tri-axial state of compression of the concrete infill increases its strength and strain capacity. Extensive studies have been conducted on the CFST and several researchers suggested empirical and theoretical formulas to predict the confinement effect and confined compressive strength of the concrete infill of the CFST. However, the previously proposed equations vary significantly because of the nature of complexity and uncertainty of the tri-axial stress state in the concrete infill. This study presented an alternative method to determine the confinement effect of the concrete infill and the axial load capacity of the stub CFST by using fuzzy logic. The focus was made on the accurate estimation of the confinement effect of the CFST by using a fuzzy-based model that makes it possible to evaluate the interaction between various parameters that affect the confinement effect. The proposed fuzzy-based model for the confinement effect and axial load capacity of the stub CFST was compared with current deign codes and the results of previous studies. It was found that the proposed fuzzy-based model provides a good prediction of the confinement effect and axial load capacity of the stub CFST. Finally, the design chart to estimate the confinement effect of the stub CFST was provided for practical design purpose.

1. Introduction

A concrete-filled steel tube (CFST) has been widely used as structural members, such as a building column and a bridge pier due to several advantages. Fig. 1 shows the example of an application of CFT member to a building column [1]. The primary advantage of CFST is that the concrete infill is confined by the steel tube, which results in tri-axial state of compression that increases the strength and strain capacity of the concrete infill. In addition, the concrete infill restrains local and global buckling of the steel tube. CFST permits rapid construction as the steel tube replaces reinforcements and eliminates the extra labor associated with formworks [2,3].

Extensive experimental and numerical studies have been conducted in the past decades to examine the confinement effect and axial load capacity of stub circular CFST [4–18] where the stub circular CFST has small length to diameter ratio so that the effect of global instability is negligible. Mander et al. [19] established the fundamental mechanisms of the confinement effect of reinforced concrete columns and several researchers [15–18] proposed the modified versions of Mander's formula to estimate the confinement effect of stub circular CFST based on statistical approaches. However, the proposed formulas vary significantly. This is mainly attributed to the nature of complexity of the tri-axial stress state in the concrete infill and each researcher considered different variables to predict the confinement effect of the stub circular CFST. In addition, some design codes [20,21] specify provisions for circular CFST under axial load. However, design codes show considerable deviations from available experimental results of the stub circular CFST [22]. Thus, a more robust empirical modeling technique that accommodates the fundamental mechanism of the confinement effect is needed to estimate axial load capacity of stub circular CFST.

In this study, an alternative method using fuzzy logic to predict the confinement effect and axial load capacity of stub circular CFST was presented. In general, fuzzy logic can be used to simulate complex engineering problems. Its feasibility as universal approximators has been proven [23]. In structural engineering practice, fuzzy logic is applied to assess various structural properties such as concrete durability and punching shear strength of the slab [24,25]. It should be noted that both random and nonrandom types of uncertainties can be considered by using fuzzy logic, while only random uncertainties can be considered in the probabilistic approaches [23,26,27]. Furthermore, it is possible to evaluate the interaction between various parameters that affect the confinement effect of the stub circular CFST by using fuzzy logic.

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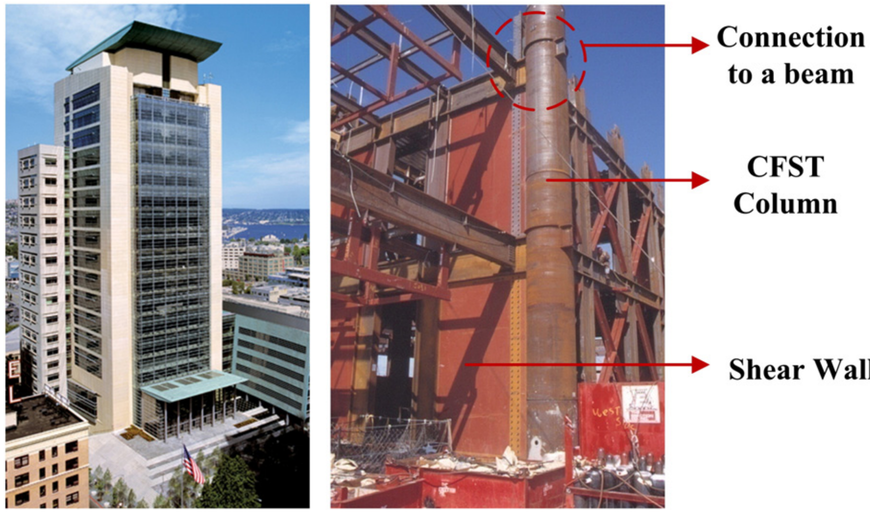

Fig. 1. Example of application of CFST member to a building column (U.S. Federal Courthouse, Seattle, WA, USA [1]).

To develop a fuzzy-based model to assess the confinement effect of the stub circular CFST, the background theory and test database were discussed first. Then, the main parameters that affect the confinement effect were investigated based on the previously proposed models. Subsequently, the Modified Learning From Example (MLFE) algorithm [23, 28] was applied to develop fuzzy rule-base. For verification purposes, the proposed fuzzy-based model was compared with the current deign codes and the results of previous studies. The comparison shows that the proposed fuzzy-based model gave a reasonable estimation of the confinement effect and axial load capacity of the stub circular CFST. Finally, design chart to estimate the confinement effect of the stub circular CFST was provided for the design purpose.

2. Background theory: confinement effect and axial load capacity of stub circular CFST

Fig. 2 shows the stress distribution of stub circular CFST under axial load where the ratio of the length, L, to outer diameter of the steel tube, D, is usually smaller than 4 for the stub CFST. The effect of global instability is negligible for the stub CFST and the maximum load capacity equals to the squash load, P_o. In Fig. 2, t is the thickness of the steel tube, f_c is the stress in concrete infill, f_s is the stress in the steel tube, f_t is the hoop stress, and f_l is the confinement stress. At early loading stages prior to the development of micro crack in the concrete infill, Poisson's ratio of the steel, υ_s, is larger than that of the concrete, υ_c. Thus, the separation may occur if the bond strength of the interface between the concrete infill and the steel tube is not sufficient. After developing the micro crack in the concrete infill under the axial load, υ_c increases and the concrete infill dilates in a lateral direction, followed by the development of the confinement stress. Thus, the concrete infill undergoes the tri-axial stress state.

When the concrete infill is subjected to the confinement stress, the uniaxial compressive strength of the confined concrete, f_{cc}, and the corresponding strain, ε_{cc}, are generally larger than those of plain concrete (f_c' and ε'_c), as shown in Fig. 3. Mander et al. [19] proposed the fundamental equation to estimate f_{cc} as a function of f_l, and it is given by

$$f_{cc} = f'_c + mf_l \quad (1)$$

where m is an empirical factor and the range of m varies from 4 to 6 [29]. For stub circular CFSTs, many researchers suggested the second term of Eq. (1), mf_l. Eqs. (2)–(4) show some of the proposed equations.

$$mf_l = \frac{1.558 f_y}{D/t} \quad (2)$$

from Sakio & Sun [15]

$$mf_l = 4.1[0.043646 - 0.000832(D/t)]f_y \quad \text{for } 21.7 \le D/t \le 47 \quad (3a)$$

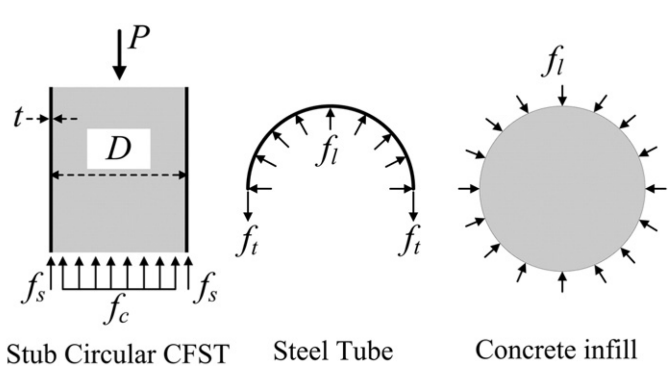

Fig. 2. Stress distribution of stub circular CFST under axial load.

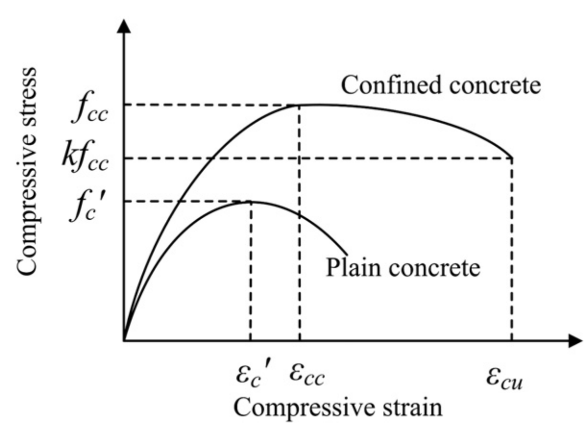

Fig. 3. Uniaxial stress–strain curve for plain and confined concrete.