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Analytical model for predicting axial capacity and behavior of concrete encased steel composite stub columns

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Abstract

The axial compressive capacity and force–deformation behavior of concrete encased steel stub columns were analytically investigated. An analytical model was developed for predicting the force–deformation response for composite stub columns with various structural steel sections and volumetric lateral reinforcement. Constitutive relationships were established for materials used in the composite cross section, which included unconfined concrete, partially and highly confined concrete, structural steel section, and longitudinal reinforcing bar. The axial capacity of composite stub columns can be determined from strengths contributed from each material component following the stress–strain relationship. Analytical results show that the axial load-carrying capacity and force–deformation behavior measured in the experiments can be accurately predicted. In addition to the lateral reinforcement, the structural steel section can provide a confinement effect on the concrete and enhance the axial capacity and post-peak strength.

Keywords: Concrete encased; Composite column; Confined concrete

1. Introduction

Concrete encased steel columns are one type of composite columns used in composite structures. The concrete encased steel composite column consists of structural steel section encased in reinforced concrete. The structural steel is rolled or built-up shape. Deriving benefits from combining the structural steel and reinforced concrete, the composite columns possess great load-carrying capacity and stiffness owing to composite action. Further, the concrete encasement can serve for fire protection. Therefore, the use of the composite columns in medium-rise or high-rise buildings has been increased significantly in recent decades [1,2].

Numerous experimental investigations have been carried out to study the ultimate strength of concrete encased steel composite columns [3–8]. Research has also been carried out on cyclic behavior of composite beam–columns [9,10]. Although the behavior of concrete encased steel composite columns has been extensively studied, many of the research works emphasized the composite columns with H-shaped structural steel section. However, other shapes of steel section such as cross- or T-shaped are generally used in composite buildings. The composite column with cross-shaped steel section is widely used in an interior column to connect four steel beams in orthogonal directions. The cross-shaped steel section is usually fabricated by welding two H-shaped steel sections together. The composite column with T-shaped steel section is usually designed for an outer column. There is very little research regarding the effect of various shapes of steel section on the axial compressive behavior of concrete encased steel columns. The concrete confinement of composite columns with various shapes of steel section is not well understood yet.

Research has been conducted to study the confinement effect of the concrete in concrete-filled steel tube (CFT) composite columns [11–16]. From previous work, it is clear that the steel tube, particularly the circular tube, can provide confinement on concrete and lead to the enhancement of strength and ductility of the CFT columns. It is of important to investigate the concrete confinement effect in the concrete encased steel composite columns. In this study, an analytical approach is developed for determining the axial compressive load–deformation relationship for concrete encased composite stub columns. The emphasis of the proposed modeling is the

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Nomenclature

A_{ch}	area of the highly confined concrete;
A_{cp}	area of the partially confined concrete;
A_{cu}	area of the unconfined concrete;
A_r	cross-sectional area of the longitudinal bars;
A_s	cross-sectional area of the structural steel section;
E_c	tangent modulus of elasticity of concrete;
E_{sec}	secant modulus of the confined concrete at peak stress;
f_c	longitudinal concrete stress;
f'_{cc}	compressive strength of the confined concrete;
f_{ch}	stress of the highly confined concrete;
f'_{co}	compressive strength of the unconfined concrete;
f_{cp}	stress of the partially confined concrete;
f_{cu}	stress of the unconfined concrete;
f'_l	effective lateral confining stress;
f_s	stress of the structural steel;
f_{sr}	stress of the longitudinal bar;
f_{ys}	yield strength of the structural steel;
f_{yr}	yield strength of the longitudinal bar;
K_h	confinement factor for highly confined concrete;
K_p	confinement factor for partially confined concrete;
P_{Analy}	analytical load;
P_{Squash}	squash load;
P_{Test}	experimental load;
ε	axial compressive strain;
ε_c	longitudinal concrete strain;
ε_{cc}	strain at maximum confined concrete stress;
$\varepsilon_{cc,p}$	strain at maximum partially confined concrete stress;
ε_{co}	strain at maximum unconfined concrete stress.

establishment of stress–strain relations for concrete confined by the lateral reinforcement and various structural steel sections. The predicted axial compressive capacity and axial load–deformation relationship were compared with available experimental results to validate the analytical modeling and investigate the effect of design variables.

2. Analytical modeling

The cross section of the concrete encased steel composite column comprises three materials, i.e., concrete, structural steel, and longitudinal reinforcing bar. For a stub column, the axial compressive capacity and axial load–deformation response can be determined based on the strain compatibility on the composite cross section. When a uniform axial compressive strain is assumed, the stress of each material of the composite column can be obtained through the constitutive model established for each material. Consequently, the axial load can be calculated by adding the axial force from each material, while the axial force is computed by multiplying the stress of material by the corresponding cross-sectional area. Furthermore, the axial load versus strain curve can be generated for the composite cross section. Several assumptions considered in this analytical model are as follows: (1) uniform distribution of compressive strain is assumed on the cross section; (2) stresses of the materials are calculated based on corresponding uniaxial stress–strain relations; (3) a confinement effect caused by the lateral reinforcement and elements of the structural steel on the concrete is considered; and (4) local buckling of the longitudinal bars and elements of the structural steel is assumed.

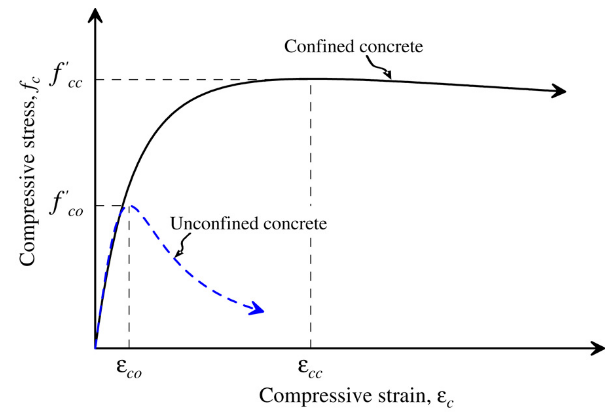

Fig. 1. Stress–strain curves for unconfined and confined concrete proposed by Mander et al. [18].

2.1. Constitutive model for concrete

The confinement effect of concrete by lateral reinforcement in a reinforced concrete column has been recognized because the lateral reinforcement can provide confining pressure to the concrete core [17,18]. The confining pressure results in an enhancement in the strength and ductility of the concrete, depending on the degree of the confining pressure. In addition to the lateral reinforcement, the confinement is also affected by other factors, such as distribution of the longitudinal reinforcement, cross section configuration, and loading type. Analytical models to predict the uniaxial stress–strain behavior for confined concrete have been proposed by researchers [17–19].

Mander et al. [18] proposed a unified stress–strain model, shown in Fig. 1, for confined concrete for members with different cross sections under various loading conditions. The longitudinal compressive stress–strain (f_c–ε_c) curve for confined concrete is given by

$$f_c = \frac{f'_{cc} x r}{r - 1 + x^r} \tag{1}$$

with

$$x = \frac{\varepsilon_c}{\varepsilon_{cc}} \tag{2}$$

$$r = \frac{E_c}{E_c - E_{\mathrm{sec}}} \tag{3}$$

where f'_{cc} is the compressive strength (peak stress) of confined concrete; ε_{cc} is the strain at maximum confined concrete stress; E_c is the tangent modulus of elasticity of the concrete; and E_{sec}