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Prediction of stress–strain behavior of spirally confined concrete considering lateral expansion

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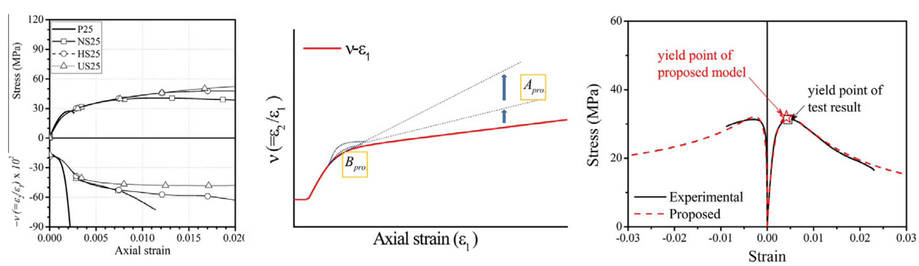
HIGHLIGHTS

- A new approach for evaluating confinement effect of confined concrete.
- Study of axial–transverse behavior of confined concrete with spiral reinforcement.
- Analysis of dilation ratio of confined concrete.

GRAPHICAL ABSTRACT



Comparison for stress-strain relationship of experimental and proposed model

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ABSTRACT

This paper proposes a new analytical model for the relationship between the axial and transverse strains of confined concrete in uniaxial compression. The proposed model was developed based on empirical data for a circular section confined by spirals. A column with a circular section and subjected to uniaxial compression was considered. The proposed model predicts the stress in the transverse confinement reinforcement to estimate the relationship between the axial strain of the column and tensile strain of the transverse confinement reinforcement. The model can also produce the axial stress–strain relationship of the confined concrete of the column. The predicted axial and transverse strains of the confined concrete section corresponded to the observed axial peak stress of a column evaluated in previous research with good accuracy. This model will be an effective tool for investigating the effect of circular spirals on the structural behavior of confined concrete and enhancing the accuracy of structural behavior analysis for a column under uniaxial compression.

1. Introduction

Recent structural design philosophies have favored ductile structural systems to allow time for evacuation and predict the collapse of the building from various disturbances such as earthquakes, tsunamis, and wind. In a reinforced concrete (RC) structure, the column is one of the most important structural members because it significantly affects the ductile behavior of the building. Hence, the structural designer is required to carefully consider the detailed design of the transverse confinement reinforcement at portions where plastic hinges will probably initiate to obtain the ductile behavior of the building.

Richart et al. [1] were the first to research the confinement effect of reinforcement on the structural behavior of RC columns. Their efforts were followed by many other researchers (Balmer [2]; Chan [3]; Roy and Sozen [4]; Soliman and Yu [5]). In the early 1970s, Sargin et al. [6], Kent and Park [7], and Popovics [8]

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Notations

A_{cc} area of core within center lines of perimeter spiral or hoops excluding area of longitudinal steel
A_e area of effectively confined core concrete
A_{El} parameters controlling the shape of the stress–strain ascending curve
$A_{Pro.}$ coefficient of parameters (f_{co}, f_y, ρ_s) for confined concrete
B_{El} parameters controlling the shape of the stress–strain descending curve
$B_{Pro.}$ coefficient of parameter (ρ_s) for confined concrete
d diameter of circular concrete core
d_{sp} diameter of spiral or hoops
e thickness of continuous confinement envelop
E_c modulus of elasticity of concrete
E_p secant modulus of confined concrete
f_c concrete stress
f_{co}, f_{cc} compressive strength of unconfined and confined concrete, respectively
f_r lateral confining stress on concrete from transverse reinforcement
f_{re} effective lateral confining stress
f_s stress of confining transverse reinforcement
f_y yield stress of confining transverse reinforcement
I'_e effective confinement index evaluate at peak strength
k_e confinement effectiveness coefficient
K strength enhancement coefficient
$k_{L\grave{e}}$ parameter of confinement model
$k_{1,El}$ peak strength enhancement factor
$k_{2,El}$ peak strain enhancement factor
$k_{1,Ra}$ coefficient that relates confinement pressure to strength enhancement
$k_{2,Ra}$ coefficient that reflects efficiency of confinement reinforcement
$k_{3,Ra}$ coefficient that reflects effect of concrete strength
$k_{1,L\acute{e}}$, $k_{2,L\acute{e}}$ parameters controlling shape of post-peak portion of stress–strain curve
r modular ratio
s pitch of spiral or hoops
s_l pitch of longitudinal reinforcement, laterally supported by corner of hoop or hook of crosstie
x strain ratio
$\alpha_{pro.}$ fitting coefficient indicating the post-gradient in dilation ratio-axial strain curve (=160)
α_s coefficient of concrete strength
β coefficient of yield strength of transverse reinforcement for stress–strain descending curve
$\beta_{pro.}$ fitting coefficient indicating the pre-gradient in dilation ratio-axial strain curve
ε_c strain of unconfined and confined concrete
ε_{co}, ε_{cc} axial strain at peak stress of unconfined and confined concrete
ε_s lateral strain at peak stress of unconfined and confined concrete
ε_1 axial strain of confined concrete
$\varepsilon_{1y,ana}$ analytical axial strain at yield of spiral reinforcement
$\varepsilon_{1y,exp}$ experimental axial strain at yield of spiral reinforcement
ε_2 lateral strain of confined concrete
$\kappa_{L\grave{e}}$ parameter used to determine if yielding of transverse reinforcement occurs at peak strength of confined concrete
$\nu_{Pro.}$ proposed strain ratio of lateral strain and axial strain ($\varepsilon_2/\varepsilon_1$) of confined concrete
ν strain ratio of lateral strain and axial strain ($\varepsilon_2/\varepsilon_1$) of confined concrete

proposed analytical models for the stress–axial strain behavior of confined concrete: $f_{co} - \varepsilon_1$. This has been quoted in many papers.

Wang et al. [9] and Ahmad and Shah [10] proposed new analytical models based on the research of Sargins et al. [6]. The research by Kent et al. [7] was followed by Park et al. [11] and Sheikh and Uzumeri [12]. Carreira and Chu [13] and Mander et al. [14] proposed new methods to determine the confinement effect of confined concrete based on Popovics' model [8].

Since the 1990s, the construction of larger and high-rise buildings have increased the demand for high-strength and high-performance materials. Hsu and Hsu [15] and El-Dash and Ahmad [16] validated the confinement effect of confined high-strength concrete on the structural behavior.

Razvi and Saatcioglu [17], Assa et al. [18], Bing et al. [19], and Légeron and Paultre [20] performed compression tests on confined concrete, where the compressive strength of concrete and yield strength of the transverse reinforcement were varied from 20 to 140 MPa and 300 to 1400 MPa, respectively. Based on the test results, these research groups proposed various analytical models.

As shown in Fig. 1, high-strength concrete confined by high-strength transverse reinforcement tends to fracture in brittle failure prior to yielding of the transverse reinforcement (Cusson and Paultre [21]). So far, the previous analytical models have not considered the brittle failure patterns of high-strength concrete confined by high-strength transverse reinforcement. If high-strength transverse reinforcement is used in the column there is a question over whether the transverse reinforcement yields at column failure. Only a few models consider the yielding of the transverse

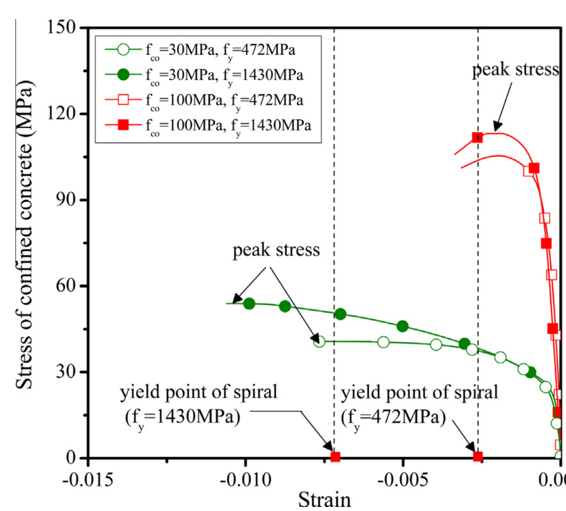

Fig. 1. Yielding point of the transverse reinforcement according to compressive strength of concrete.

reinforcement (Razvi and Saatcioglu [17]; Légeron and Paultre [20]). However, they are limited in terms of developing the method for prediction of yield of transverse reinforcement confining the core concrete of column section. Also, the tensile strain and stress of transverse reinforcement in column section were not considered in their researches. Since 2000, there are a few research on the lat-