Construction and Building Materials 147 (2017) 847–857

Contents lists available at ScienceDirect

Construction and Building Materials

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

Two models for evaluating the bond behavior in pre- and post-yield phases of reinforced concrete

Binbin Zhou [a,*], Ruoyang Wu [b], Jian Feng [a]

[a] The National Prestress Engineering Research Center, Southeast University, Nanjing, China
[b] The Department of Civil and Environmental Engineering, University of Utah, Salt Lake City, USA

HIGHLIGHTS

- The mean bond stress model, associated with steel strain level, is developed to simply predict bond characteristics in pre- and post-yield phases.
- The bond-strain model is presented to describe the bond behavior in terms of reinforcement strain.
- The mean bond stresses representing bond behavior in several characteristic phases of reinforced concrete members are suggested.

ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form 8 April 2017
Accepted 10 April 2017
Available online 9 May 2017

Keywords:
Mean bond stress model.
Bond-strain model
Interfacial fracture energy
Slip
Strain (stress) level

ABSTRACT

The performance and behavior of reinforced concrete structures at serviceability limit state and at ultimate limit state highly rely on the bond interaction between reinforcement and surrounding concrete; therefore a proper evaluation regarding the bond behavior under corresponding state is particularly critical. However, it is not easy to implement the common bond models, characterized by nonlinearity and affiliated with the variable of slip, into practical design and analysis. In this paper, the mean bond stress model associated with steel strain (stress) level and the bond-strain model representing the relationship between bond stress and reinforcement strain are developed to simplify and improve the normal analysis on bond behavior in pre- and post-yield phases. Compared with the results of some well-known experimental campaigns, the proposed models indicate a good agreement with the bond behavior at pre- and post-yield stages. Finally, a thorough discussion about the values of mean bond stresses is carried out; the suggested values considering bond characteristics in several phases of reinforced concrete members are presented by a series of analytical parametric studies on test results in the literature.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

In order to precisely predict some phenomena of structural concrete such as cracking, tension stiffening, and ductility, the bond behavior between reinforcement and concrete should be taken into account. Consequently, many bond laws have been developed over the past decades. Eligehausen et al. [1] have conducted plenty of pull-out tests and inferred a local bond-slip model for the ribbed bars with good confinement conditions. Since then the CEB-FIP Model Code 1990 (MC90) [2] and the Model Code 2010 (MC2010) [3] subsequently have referred to the model of Eligehausen et al. and presented Eq. (1) to describe the ascending portion of bond response.

$$\tau = \tau_{max}\left(\frac{\delta}{\delta_1}\right)^{\alpha} \tag{1}$$

where τ_{max} is the bond strength (MPa); δ_1 is the slip corresponding to bond strength and depends on the confinement conditions (mm); and $0 \leqslant \alpha < 1$ being generally 0.4.

Most bond models were derived from the pull-out tests with short anchorage lengths and reveal the bond characteristics of bars at elastic state. Nonetheless, a portion of rebar in specimen with a long anchorage length usually enters into the plastic stage before being extracted from concrete, and it is common for reinforced concrete structures in reality. With a large tension applied to the rebar, the circumferential contraction of rebar due to Poisson effect tends to induce the diminishment of outward pressure and further result in the decrease in bond stress; it becomes particularly pronounced after yielding [4]. Hence the general bond models, inferred from pull-out tests with short anchorage lengths, cannot precisely predict the bond behavior of specimens with long anchorage lengths.

More recently, great efforts have been made to develop some bond models [3,5–17] to predict the bond behavior of

* Corresponding author.
E-mail address: binzhouseu.edu@gmail.com (B. Zhou).

http://dx.doi.org/10.1016/j.conbuildmat.2017.04.067
0950-0618/© 2017 Elsevier Ltd. All rights reserved.

reinforcement after yielding. Shima et al. [5] first performed a series of tests on long anchored reinforcement with an embedment length of 50∅, which is long enough to avoid free end slip, to study the bond characteristics of bars at pre- and post-yield stages and formulated a bond model revealing a bond stress-slip-strain relationship, described by Eq. (2).

$$\tau(\delta,\varepsilon_s) = 0.73 f_c \left[\ln\left(1+5000\frac{\delta}{\varnothing}\right)\right]^3 \frac{1}{1+\varepsilon_s\cdot 10^5} \quad (2)$$

where τ is the bond stress (MPa) and is the function of slip and steel strain; f_c is the concrete compressive strength (MPa); δ is the slip between bar and concrete (mm); ε_s is the steel strain; ∅ is the bar diameter (mm).

In addition, a unique bond slip-strain law, illustrated by Eqs. (3)–(7), has been presented in their research work.

$$s = \frac{\delta}{\varnothing} K_{fc} \quad (3)$$

$$K_{fc} = (f_c/20)^{2/3} \quad (4)$$

$$s = \varepsilon_s(2+3500\varepsilon_s);\, \varepsilon_s \leqslant \varepsilon_y \quad (5)$$

$$s = s_y;\, \varepsilon_y < \varepsilon_s \leqslant \varepsilon_{sh} \quad (6)$$

$$s = s_y + 0.047(f_u - f_y)(\varepsilon_s - \varepsilon_{sh});\, \varepsilon_s > \varepsilon_{sh} \quad (7)$$

where s is the dimensionless slip normalized with regard to the bar diameter and multiplied by a factor (K_{fc}) to consider the variations in concrete strength; δ is the slip between bar and concrete (mm); f_c is the concrete compressive strength (MPa); ε_s is the steel strain; ∅ is the bar diameter (mm); ε_y is the steel yield strain; ε_{sh} is the steel strain at the onset of hardening; and f_y and f_u are the yield strength and tensile strength of steel (MPa), respectively.

Another fulfilling experimental program to explore the bond behavior of bars with adequate anchorage lengths was conducted by Engström et al. [6,7]. With the sophisticated specimens sketched in Fig. 1, the bond-slip relationship was indirectly evaluated by analysis on the crack width, w, and tensile force, F. Then a specific bond model for ribbed bars at pre- and post-yield stages was formulated, as shown in Fig. 2. In this figure, the curve I, similar to the bond model suggested by the MC90 [2], describes the bond behavior of reinforcement under elastic state. As the steel bar subjected to yielding is considered, the curve II is able to relatively precisely predict the global bond response. The detailed illustrations about relevant parameters describing the curves are listed below:Curve I: $\delta_1 = 1.0mm$; $\delta_2 = 3.0mm$; δ_3 = clear rib spacing; $\delta_4 = 3\delta_3$; $\tau_{max} = 0.45 f_{cm}$; $\tau_f = 0.4\tau_{max}$.Curve II: $\delta_{yf} = \delta_y + 2.5mm$; $\delta_5 = 2\delta_3$; $\tau_{yf} = 0.2\tau_{max}$;where f_{cm} is the mean value of compressive strength of concrete (MPa) and δ_y is the slip at yielding (mm).

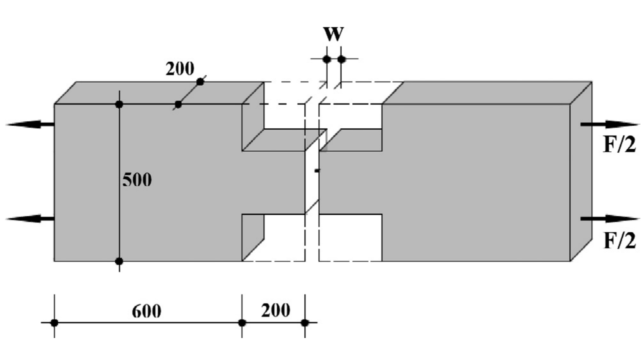

Fig. 1. Geometry of test specimens of Engström et al. [7].

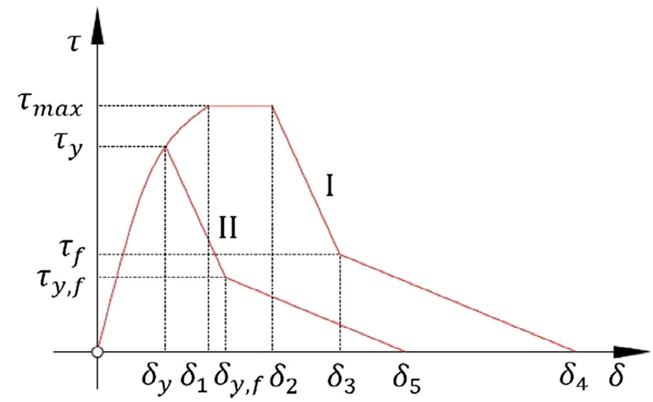

Fig. 2. Bond-slip model proposed by Engström et al. [6].

Note that there are no specific definitions about bond strength at yielding, τ_y, and its corresponding slip, δ_y. To acquire the two values, the cumbersome solutions of equilibrium and compatibility equations based on the overall behavior of anchorage region are required [4].

Bigaj et al. [8,9] have also presented a bond model, which has been verified through their experimental project resembling that performed by Shima et al. [5], to illuminate the confinement effect on bond behavior in terms of fracture mechanics, whereby the influence of steel strain on bond behavior is effectively predicted.

With the aim of simply addressing bond behavior in design practice and analysis, Marti and Sigrist et al. have proposed the Tension Chord Model (TCM) [10–12] that hypothesizes a rigid-plastic bond law affiliated with two mean bond stresses at pre- and post-yield stages (Eq. (8)).

$$\tau(\varepsilon_s) = \begin{cases} 0.6 f_c^{2/3};\ \varepsilon_s \leqslant \varepsilon_y \\ 0.3 f_c^{2/3};\ \varepsilon_s > \varepsilon_y \end{cases} \quad (8)$$

where ε_s is the steel strain; ε_y is the steel yield strain; f_c is the concrete compressive strength (MPa). The two constant values of mean bond stresses were derived from the nonlinear bond-slip law, which does not consider the effect of reinforcement yielding on bond, according to the principle of force equilibrium. Recently, in view of some comparisons with experimental results, some researchers [18,19] have questioned the two values and presented their suggestions.

Miguel et al. [14] have implemented bond correction factors, implicating the effect of bar strain on bond behavior, into the bond laws which were deduced from pull-out tests characterized by short anchorage lengths. It is the simple treatment that inspires some researchers to develop various bond factors and, furthermore, a similar factor, given by Eq. (9), was adopted in the MC 2010 to consider the influence of reinforcement strain on bond response.

$$\Omega_y(\varepsilon_s) = \begin{cases} 1.0;\ \varepsilon_s \leqslant \varepsilon_y \\ 1.0 - \left[0.85\cdot\left(1-e^{-5a^b}\right)\right];\ \varepsilon_s > \varepsilon_y \end{cases} \quad (9)$$

$$a = \frac{\varepsilon_s - \varepsilon_y}{\varepsilon_u - \varepsilon_y};\ b = \left[2.0 - \frac{f_t}{f_y}\right]^2 \quad (10)$$

where $\Omega_y(\varepsilon_s)$ is reduction factor; a and b are calculated by Eq. (10); ε_s is the steel strain; ε_y is the yield strain of steel; ε_u is the ultimate tensile strain of steel; f_t and f_y are steel tensile strength and yield strength(MPa), respectively.

There is a unique relationship between bond stress, slip, and strain if the embedment length of reinforcement in the pullout

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات