

## 論文 Concrete Cover Effect on Tension Stiffness of Cracked Reinforced Concrete

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**ABSTRACT:** The aim of the present study is to check the effect of non-sufficient concrete cover on the tension stiffness of reinforced concrete. Splitting cracks are predicted by solving equilibrium among radial bond stresses, softening tensile stresses of splitting concrete planes and transverse stress on reinforcement. The bond behavior after splitting cracks is the point of study. The analytical model is derived from the micro-bond characteristics. An experimental program was carried out to verify the analysis. The analysis fairly agrees with the reality.

**KEY WORDS:** Bond-slip-strain, tension stiffening, crack spacing, confining pressure, splitting

### 1. INTRODUCTION

When the concrete cover is not sufficient, longitudinal cracks, named as splitting cracks, are formed parallel to reinforcing bars. The occurrence of these cracks is a result of the three dimensional bond transfer mechanisms. The deformed bars' lugs induce bearing stresses in the concrete, resulting in conical compressive struts. The conical bond forces between bar and concrete can be resolved into radial and tangential components. Usually, the tangential one is called bond stress, whereas the radial one is called confining stress. The radial stresses can be analogues to hydraulic pressure acting on a thick-walled concrete ring. When the tangential ring stresses exceed the cracking strength, the splitting crack is formed. The bond behavior for concrete having such cracks was studied by Gambarova et al.[5]. He tested many specimens with artificial splitting crack. Changing the splitting crack width and the confining pressure on the bars, an empirical formula was proposed for bond stresses after cover splitting. Abrishami and Mitchell [9] studied the splitting cracks' effect on tension stiffening. Specimens with shallow depth were targeted. Here, the concrete cover was insufficient from both sides. The common members of civil structures are deep and the cover problem is that of one side cover. Therefore, a less effect of splitting crack would exist. Salem and Maekawa [10] derived tension stiffening from local bond stress development by assuming thick covers. The aim of this study is to derive smeared model for reinforced concrete in tension from microscopic behavior, taking into account the possible reduction in bond stresses due to non-sufficient cover accompanying longitudinal splitting cracks.

### 2. SPLITTING BOND STRESS

#### 2.1 MEMBERS WITHOUT TRANSVERSE REINFORCEMENT

The principal direction of bond forces between deformed reinforcing bar and surrounding

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concrete makes an angle with the bar axis. The bond forces can be resolved into radial and tangential components. Usually, the tangential one is called bond stress, whereas the radial one is called confining stress or pressure. The angle of inclination denoted by  $\alpha$  ranges from 45 to 80 degrees as reported by Goto [2]. The radial stresses due to bond action act like hydraulic pressure acting on a thick-walled concrete ring. An elastic solution for the stresses in a thick-walled cylinder subjected to internal pressure is given by Timoshenko[1], and Avalué et al.[8] as,

$$\sigma_r = p R_{cr}^2 \left( \frac{1 - \frac{R_{max}^2}{r^2}}{R_{max}^2 - R_{cr}^2} \right), \quad \sigma_t = p R_{cr}^2 \left( \frac{1 + \frac{R_{max}^2}{r^2}}{R_{max}^2 - R_{cr}^2} \right) \quad (1)$$

where,  $\sigma_r$ ,  $\sigma_t$ : radial and tangential stresses at radial distance  $r$  from the centre of the bar,  $p$ : radial pressure,  $R_{cr}$ : radius of cracked concrete zone,  $R_{max}$ : cover of concrete +  $\Phi/2$  and  $\Phi$ : bar diameter.

These equations are valid for the non-cracked concrete. However, in cracked concrete, the tension fracturing develops as illustrated in Fig. 1.

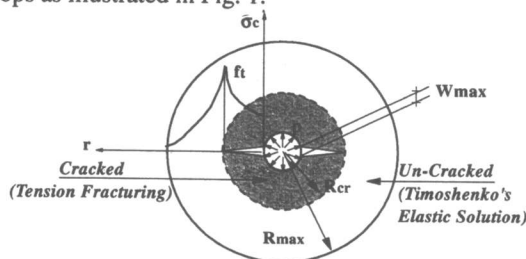


Fig. 1 Tangential Stress in Cracked and Non-Cracked Concrete

According to Avalué et al.[8], the bond pressure which causes a splitting crack of radius  $R_{cr}$  can be computed by equilibrating the bond pressure  $p$  with the tangential stresses in both the cracked and non-cracked concrete as,

$$p = \frac{2f_t}{\Phi} \left( R_{cr} \left( \frac{R_{max}^2 - R_{cr}^2}{R_{max}^2 + R_{cr}^2} \right) + \int_{\Phi/2}^{R_{cr}} \left( \frac{\sigma_c(w(r))}{f_t} \right) dr \right) \quad (2)$$

where,  $w(r)$ , is the splitting crack width at radius  $r$  and,  $\sigma_c(w(r))$ , is the residual tensile stresses corresponding to crack width equal to  $w(r)$ . The tension softening model adopted here is given by Uchida et al.[7] as,

$$\sigma_c(w(r)) = f_t \left( 1 + 0.5 \left( \frac{f_t}{G_f} \right) w(r) \right)^{-3} \quad (3)$$

where  $G_f$  is the fracture energy ranging from 0.1 to 0.15 kgf/cm for plain concrete.

In Equation (2), Avalué assumed two propagating splitting cracks. This assumption agrees with the experimental observation of Morita and Kaku [3] who reported that two or three splitting cracks propagate to surface of a concrete cylinders in pull-out tests. Moreover, in structural members, this is usually the case where splitting cracks propagate towards the side of less cover. Avalué also assumed tangential strain compatibility by equating the circumferential elongation at  $r$  equal to  $\Phi/2$  and  $r$  equal to  $R_{cr}$  with the concrete elasticity denoted by  $E_c$  as,

$$2\pi R_{cr} \frac{f_t}{E_c} = 2w_{max} + \left( 2\pi \frac{\Phi}{2} - 2w_{max} \right) \frac{\sigma_c(w_{max})}{E_c} \quad (4)$$