

論文

[2114] Deformational Model for Solid Phase in Fresh Concrete under Compression (Single Materials)

Somnuk TANGTERMSIRIKUL* and Kohichi MAEKAWA**

1. INTRODUCTION

At present there are many well-studied constitutive models for predicting deformational behavior of hardened concrete. With the use of these models, the deformational behavior of hardened concrete structures can be predicted. In the aspect of fresh concrete, one rational method is to treat fresh concrete as a multi-phase material. Analysis of dynamics of water in fresh concrete under compression is one of the example which treats fresh concrete as multi-phase material[1]. To predict the deformational and water-segregation behavior of fresh concrete as multi-phase material, the deformational models of every phase are essential especially for the complicated solid phase. Hence the idea for two-dimensional model for predicting the deformation of solid phase which is the mixture of aggregates and cementitious material was proposed by the authors. In this paper, the idea for single materials, which are coarse aggregate, fine aggregate and powder materials separately, is proposed and that of the mixtures will be proposed following this paper. Various parameters indicating physical properties of the particles are considered. Lateral stress coefficient was derived for the case of uni-axial confined compression. Uni-axial confined compression tests of dry materials were performed to illustrate the applicability.

2. THEORETICAL IDEA OF THE MODEL

The idea for two-dimensional constitutive model of solid phase under compression is proposed in this paper. The single materials are considered composed of particles which are contacting each other. Each contact has its own contact angle (θ) and the density distribution of the contact angle is assumed to be $\Omega(\theta)$. $\Omega(\theta)$ can be explained simply as it represents the ratio of numbers of contact at contact angle θ to the total numbers of contact. At each contact plane, the force system acting on the contact is calculated and integrated over contact angle θ to obtain equilibrium. The force system contains frictional force in the tangential direction to the contact plane and normal force due to deformation normal to the contact plane. Stress-strain relation which is applied for relating the deformation normal to the contact plane with the corres-

* Graduate student, University of Tokyo

** Associate professor, University of Tokyo

ponding stress is assumed. Friction is treated as Coulomb's friction. Contact area increases as the deformation progresses and it is affected by particle shape, size and grading. Re-arrangement of particles is also the significant factor especially for small sized and/or high frictional particles.

2.1 DENSITY FUNCTION FOR CONTACT ANGLE

Particles are considered having a density function for contact angle as in Fig.1. Li and Maekawa[2] proposed a different function to evaluate the effective contact area to model the shear transfer across crack. Here it is reasonable to suppose that there are negligible contacts with contact angle normal and parallel to the principal strain direction (θ equals 0 and $\pi/2$) but most are contacting such that θ is nearly or just $\pi/4$. Then the function for contact angle is assumed as

$$\Omega(\theta) = \sin(2\theta) \quad (1)$$

which satisfies the mentioned condition.

2.2 DEFORMATION AT A CONTACT

Consider a unit volume of which each side has unit length so that deformations, ω_θ and $\delta\theta$, can be related to strains, ε_z and ε_y , in the analysis. Fig.2 shows 2-dimensional displacement compatibility for a contact at contact angle θ . From the geometry in Fig.2, ω_θ and $\delta\theta$ can be related to ε_y and ε_z by

$$\omega_\theta = \varepsilon_z \cdot \cos\theta + \varepsilon_y \cdot \sin\theta \quad (2)$$

$$\delta\theta = \varepsilon_z \cdot \sin\theta - \varepsilon_y \cdot \cos\theta \quad (3)$$

when ε_{xy} equals zero since the co-ordinate axis coincides with the principal strain direction.

2.3 STRESS-STRAIN RELATIONSHIP FOR NORMAL DIRECTION

The stress-strain relationship for relating the normal stress ($\sigma_{c\theta}$) to the corresponding deformation (ω) under monotonic loading condition is assumed to be linear as

$$\sigma_{c\theta} = E_c \cdot \omega_\theta \quad (4)$$

2.4 FRICTION (SHEAR COMPONENT)

Coulomb's friction law is assumed to be applicable for the shear component. For simplicity the frictional stress is assumed constant independent on slip δ as in the following expression

$$f_\theta = \mu \cdot \sigma_{c\theta} \quad (5)$$

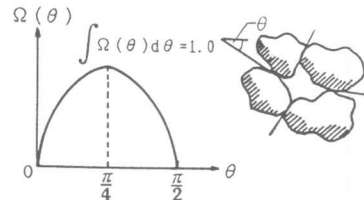


Fig.1 Density function of contact angle

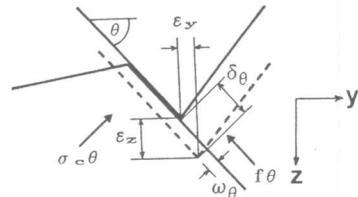


Fig.2 Initial and deformed configuration of a contact

$\sigma_{c\theta}$ and $f\theta$ are illustrated in Fig.2.

2.5 EQUILIBRIUM EQUATION

The local force system acting on the contact at contact angle θ can be transformed to be the force in the global coordinate system as

$$F_{z\theta} = (\sigma_{c\theta} \cdot \cos\theta + f\theta \cdot \sin\theta) \cdot A_{c\theta} \quad (6)$$

$$F_{y\theta} = (\sigma_{c\theta} \cdot \sin\theta - f\theta \cdot \cos\theta) \cdot A_{c\theta} \quad (7)$$

Equilibrium is taken by integrating the multiplication product of force with the density function of the contact angle in the global coordinate over contact angle from $\theta=0$ to $\pi/2$ and equate the integral to the external force as

$$\sigma_z \cdot A_z = \int_0^{\pi/2} \Omega(\theta) \cdot F_{z\theta} \cdot d\theta \quad (8)$$

$$\sigma_y \cdot A_y = \int_0^{\pi/2} \Omega(\theta) \cdot F_{y\theta} \cdot d\theta \quad (9)$$

Substituting (6) and (7) into (8) and (9) and since $A_y = A_z = 1$, we obtain the principal stresses

$$\sigma_z = \int_0^{\pi/2} \Omega(\theta) \cdot (\sigma_{c\theta} \cdot \cos\theta + f\theta \cdot \sin\theta) \cdot A_{c\theta} \cdot d\theta \quad (10)$$

$$\sigma_y = \int_0^{\pi/2} \Omega(\theta) \cdot (\sigma_{c\theta} \cdot \sin\theta - f\theta \cdot \cos\theta) \cdot A_{c\theta} \cdot d\theta \quad (11)$$

Knowing the function for contact area ($A_{c\theta}$), one can solve Eqs. (2),(3),(4),(5),(10) and (11) to obtain the 2-dimensional stress-strain relationship of the single materials.

The lateral stress coefficient (K_σ) can be obtained once σ_z and σ_y are known by using the following expression

$$K_\sigma = \sigma_y / \sigma_z \quad (12)$$

2.6 CONTACT AREA

The factors affecting contact area of the particles are size, shape, grading and re-arrangement of the particles. One significant phenomenon to be accounted for is the increasing of contact area as the deformation progresses. This phenomenon is taken into account in this study by assuming that contact area of a contact angle θ increases depending on the amount of slip at that contact ($\delta\theta$). Contact area at a contact angle θ can be expressed as

$$A_{c\theta} = (A_{c\theta_0} + \int dA_{c\theta}) \cdot \phi \quad (13)$$

Regarding geometry in Fig.2 the summation of contact area increment can be obtained from (considering unit volume so that a unit width can be applied)