CS 1 - 3〔V〕

MACRO-ELEMENT FOR ANALYTICAL MODELING OF CONCRETE

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1. INTRODUCTION

Concrete is a composite material consisting of hard inclusions (aggregate pieces), embedded in a softer matrix (mortar) (cf. Fig.1). For material modeling of such a system, concrete is considered as a system of perfectly rigid particles (elements) interacting at interfaces according to a given force-displacement relationship. Here, application of the new particle spring model has been sought because this model has been proved to be effective and suitable for analysis of nonlinear problems with large plastic deformation. It is also suitable for discretizing a specimen if for a particular type of loading, the failure mode can be roughly assumed. In the present case of concrete, the macro-element has been taken as a unit for representing one block of inhomogeneous portion of concrete, discretizing the block by centrally placed aggregate sorrounded by mortar (cf. Fig.2). This macro-element [1] is used in this analysis using the concept of the particle spring model.

2. PARTICLE SPRING MODEL FORMULATION

In this model the element node is considered to be at the centroid of the element and consequently the concept of superposition of element nodes cannot be applied but use of elements of arbitrary shape gives the advantage to make no distinction among the beam, plate and solid elements. Here two rigid bodies are considered to be connected by two different types of springs K_n and K_s perpendicular and parallel to the surface of contact, respectively. Centroidal degrees of freedom for each rigid body are denoted by two translational displacements (U_G, V_G) and one rotation (θ_G). The rigid bodies are supposed to undergo infinitesimal rigid body movements of their centroids. Then the displacement U of an arbitrary point P in the rigid body of any element can be given by the following vector equation.

$$U = U_G + O * (R - R_G) \qquad (1)$$

where

U_G displacement vector of element centroid
O infinitesimal rotation vector
$R - R_G$ position vector of a point to a local coordinate system at centroid of body

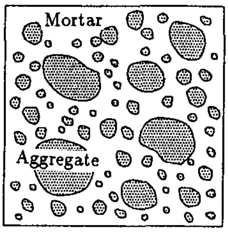

Fig.1 Internal structure of concrete

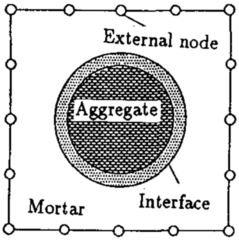

Fig.2 Macro-element

For the present modeling, two dimensional plane strain case is used. Considering a set of rigid bodies of triangular shape and assuming them to be in equilibrium with external loads and the reaction forces distributed over the spring system on the contact surface of two adjacent bodies, two such bodies are taken under consideration. The displacement vector of arbitrary point P(x,y) in body 1 and 2 (cf. Fig.3) is represented by $\{\delta\}$, where $\{\delta\} = [\delta_n, \delta_s]$ and δ_n and δ_s are the components in the perpendicular and parallel direction respectively to the plane in contact.

The force-displacement relationship can be achieved by virtual work equation which includes the stiffness matrix [D], consisting of the spring constants k_n and k_s for normal and tranverse springs respectively.

$$\{\sigma\} = [D].\{\delta\} \qquad (2)$$

$$\sigma_n = k_n.\delta_n \qquad (3)$$

$$\tau_s = k_s.\delta_s \qquad (4)$$

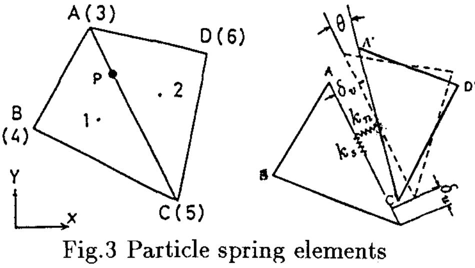

Fig.3 Particle spring elements

For the plastic deformation after yielding, the Drucker-Prager type yield surface (cf. Fig.4) for loading and failure is used for the case of concrete which is a pressure-dependent material. The yield function F is represented as follows.

$$F(I_1, J_2) = \alpha I_1 + \sqrt{J_2} - k = 0 \tag{5}$$

where I_1, J_2 are the stress invarients and α, k are the positive material constants. For the known values of c, cohesion and ϕ, the angle of internal friction of material, α and k can be defined in various ways.

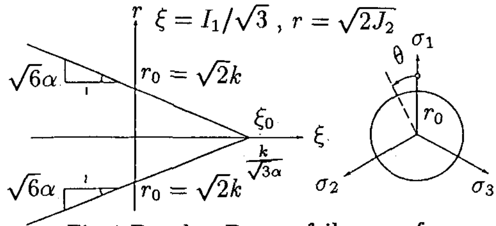

Fig.4 Drucker-Prager failure surface

3. NUMERICAL SIMULATION

The macro-element used in this study is shown in Fig.5. Changing the D/L ratio, different types of macro elements can be made. Here, D and L stand for the diameter of the aggregate and the side length, respectively. Each macro element has 128 triangular elements for mortar, 16 triangular elements for aggregate and 16 line elements for boundary conditions. The concrete specimen (cf. Fig.6) can be modeled by combining different types of macro elements. Present study has been done on a single macro element (2 cm x 2 cm). The element is subjected to uniform downward vertical loading on the top surface and restrained vertically at the bottom. The loading has been incremented step by step up to global failure. The displacement, normal stress and shear stress diagrams are shown in Figs.7-8. The numerical simulation gives a look of the internal structural condition of the specimen. In the simulation, we can get an idea of the individual component like aggregate or mortar during the process of loading. It gives the internal stress distribution pattern, internal structural change such as cracking, idea of prediction of damage assesment of a structure by observing the progress of failure. From the overall deformation shape the influence of the component parts can also be predicted.

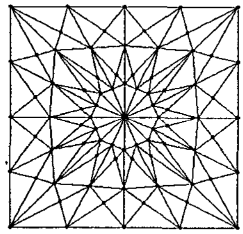
Fig.5 Macro-element

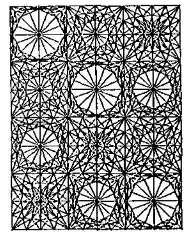
Fig.6 Concrete specimen

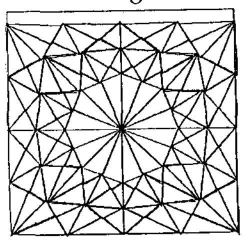
Fig.7 Displacement diagram

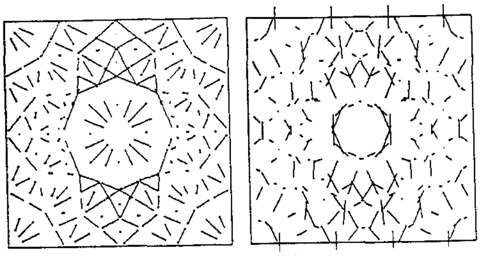
(a) Shear stress (b) Normal stress

Fig.8 Shear and Normal stress diagram

4. CONCLUTIONS

This particle spring model is a comparatively better choice than the other existing numerical models. Using this method, stress analysis of deformable bodies under contact will be possible in an iterative way. In any element, total number of degrees of freedom never exceeds 3 because it is assumed rigid, which is advantegeous. Again in the material modeling, from the concept of the individual component constitutive relationship we can get the global constitutive property of the specimen. In the parametric study, the effect of volume ratio of the component elements, grading and the spatial distribution of coarse aggregate, shape of the specimen can also be taken into account to see the effect on the overall mechanical behavior of the specimen.

REFERENCE

1. T. Tsubaki, M.K. Das, K. Shitaba, "Numerical Simulation to Analyze Statistical Variation of Creep of Concrete," Trans. of the 11th Internatiol Conference on SMiRT, Vol.H, 1991, pp.175-180.