8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

MICROPLANE MODELING OF DAMAGE AND FRACTURING IN PARTICULATE AND FIBER COMPOSITES AND BIO-MATERIALS

Zdenek P. Bažant[1], Ferhun C. Caner[2], Christian Hoover[1] and Zaoyang Guo[3]
[1]Northwestern University, 2145 Sheridan Road, CEE, Evanston, IL 60208; z-Bažant@northwestern.edu
[2]UPC, Barcelona, Spain; and Visiting Scholar at Northwestern University.
[3]University of Glasgow, Glasgow, U.K.; formerly Postdoctoral Res. Associate, Northwestern University.

ABSTRACT

The classical constitutive relations expressed in terms of stress and strain tensors and their invariants are attractive by their simplicity but pose difficulties when trying to model the full intricate response of quasibrittle materials such as concrete, rock and polymer-fiber composites. For example, a relation between I_1 and J_2 characterizes internal friction only in a very crude way but cannot capture frictional slip that occurs on only one plane of a distinct orientation. The same is true of oriented microcracking. A more powerful constitutive model appears to be the microplane approach, in which the oriented character of microcraking and slip is captured by writing the constitutive relations in terms of stress and strain vectors acting on a generic plane of any orientation within the material, called the 'microplane'.

The advantages of the microplane modeling approach are discussed. They include: automatic representation of the vertex effect, deviations from normality, cross effects such as pressure sensitivity and dilatancy, Bauschinger effect and hysteresis. Realistic generalization for anisotropic material properties is possible.

In microplane models, the relation to continuum tensors is obtained by assuming the strain (or stress) vector on the microplane to be a projection of the strain (or stress) tensor, and by using a variational principle to obtain the response stress (or strain) tensor, which leads to integration (or summation) over planes of all orientation. More fundamentally, the microplane model automatically ensues upon assuming the Helmholtz' free energy density to be a sum of the free energy densities associated with microplanes of all possible orientations. In numerical practice, only a finite number of discrete microplanes is used, based on an optimal Gaussian integration formula for the surface of a unit hemisphere.

The lecture begins by discussing the characteristic proportional, nonproportional and cyclic uni-, bi-, and triaxial tests of concrete that must be correctly reproduced, and then outlines microplane model M4 for concretes which can describe these tests, along with extensions to capture distinct widely opened fractures. In contrast to Taylor models for non-softening plasticity, softening damage requires that the strain (rather than stress) vectors be the projections of the strain (rather than stress) tensors, which is called a kinematic constraint (in contrast to the static constraint). Arbitrarily large finite strains are considered. The rate effects are included according to the activation energy of fracture growth and viscoelasticity of matrix. Generalizations to porous rocks, fiber reinforced concrete and orthotropic laminates are also described. One aspect that is much less important for high-rate applications than for static loading is the spurious localization of softening damage. Implementation of a nonlocal approach with a characteristic material length, needed for preventing spurious localization with mesh sensitivity and for capturing the energetic (non-statistical) size effect, is briefly addressed.

The lecture presents several new applications of the microplane modeling concept. One is the modeling of distributed fracturing in braided fiber-polymer composites, which captures the effect of fiber waviness, the transverse splitting stresses due to braiding, and a combination with damage model for the polymer matrix. Another is an improved microplane model for fiber-reinforced concrete exploiting a spectral positive-negative partitioning of the strain tensor. An application to the modeling of large strain behavior of human annulus fibrosus is also discussed. The lecture concludes by summarizing large-scale simulations of missile penetration and groundshock at WES, and applications in a commercial implicit code (ATENA, Cervenka Co.)

REFERENCES

Bažant, Z.P., and Planas, J. (1998). "Fracture and Size Effect in Concrete and Other Quasibrittle Materials." CRC Press, Boca Raton and London.

Bažant, Z.P., Caner, F.C., Carol, I., Adley, M.D., and Akers, S.A. (2000a). "Microplane model M4 for concrete: I. Formulation with work-conjugate deviatoric stress." J. of Eng. Mech. ASCE 126, 944-953.

Bažant, Z.P., and Caner, F.C. (2005). "Microplane model M5 with kinematic and static constraints for concrete fracture and anelasticity." J. of Engrg. Mech. ASCE 131 (1), 31-47.

Bažant, Z.P., Adley, M.D., Carol, I., Jirasek, M., Akers, S.A., Rohani, B., Cargile, J.D., and Caner, F.C. (2000b). "Large-strain generalization of microplane model for concrete and application." J. of Engrg. Mechanics ASCE 126 (9), 971-980.

Bažant, Z.P., Caner, F.C., Adley, M.D., and Akers, S.A. (2000c). "Fracturing rate effect and creep in microplane model for dynamics." J. of Engrg. Mechanics ASCE 126 (9), 962-970.

Bažant, Z.P. and Oh, B.-H. (1983a). "Microplane model for fracture analysis of concrete structures." Proc., Symp. On the Interaction of non-Nuclear Munitions with Structures, held at U.S. Air Force Academy, Colorado Springs 49-53.

Bažant, Z. P., and Oh, B.-H. (1985). "Microplane model for progressive fracture of concrete and rock." J. of Engrg. Mechanics, ASCE 111, 559-582.

Brocca, M., and Bažant, Z.P. (2001a). "Microplane finite element analysis of tube-squash test of concrete with shear angles up to 70^{o}, Int. J. for Numerical Methods in Engrg. 52, 1165-1188.

Brocca, M., and Bažant, Z.P. (2001b). "Size effect in concrete columns: Finite element analysis with microplane model." J. of Structural Engineering ASCE 127 (12), 1382-1390.

Caner, F.C., and Bažant, Z.P. (2000). "Microplane model M4 for concrete: II. Algorithm and Calibration." J. of Engrg. Mechanics ASCE 126 (9), 954-961.

Caner, F.C., Bažant, Z.P., and Cervenka, J. (2002). "Vertex effect in strain-softening concrete at rotating principal axes." J. of Engrg. Mechanics ASCE 128 (1), 24-33.

Carol, I., and Bažant, Z.P. (1997). "Damage and plasticity in microplane theory." Int. J. of Solids and Structures 34 (29), 3807-3835.

Carol, I. (2004), Jirasek, M., and Bažant, Z.P.. "A framework for microplane models at large strain, with application to hyperelasticity." Int. J. of Solids and Structures 41, 511-557.

Cervenka, J., Bažant, Z.P., and Wierer, M. (2005). "Equivalent localization element for crack band approach to mesh-sensitivity in microplane model." Int. J. for Numerical Methods in Engrg. 62 (5), 700-726.

Cusatis, G., Beghini, A., and Bažant, Z.P. (2007). "Spectral Stiffness Microplane Model for Quasi-Brittle Composite Laminates." J. of Applied Mechanics ASME, in press

Jirasek, M., and Bažant, Z.P. (2002). “Inelastic Analysis of Structures.” J. Wiley, London and New York.

Caner, F.H., Guo, Z., Moran, B., Bažant, Z.P., and Carol, I. (2007). ``Hyperelastic anisotropic microplane constitutive model for annulus fibrosus." ASME J. of Biomechanical Engineering 129 (Oct.), 632--641.