A PLASTICITY FORMULATION FOR CYCLIC INELASTIC STRUCTURAL ANALYSIS

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SUMMARY

Development of suitable constitutive equations remains a major problem in the inelastic analysis of structures under cyclic loading conditions. Inelastic material behavior under cyclic loading conditions differs significantly from that under monotonic loading due to various cycle dependent phenomena—such as cyclic hardening, cyclic softening, cyclic relaxation, and most important of all "memory" of prior cyclic history. The material constants in the current constitutive models (plasticity theories) being used are, in general, obtained from the observed material behavior under uniaxial monotonic loading. Consequently, such theories are unable to adequately predict cyclic phenomena mentioned above. This paper presents a combined isotropic-kinematic hardening plasticity formulation appropriate for both monotonic and cyclic multi-axial loading conditions.

A recent study of a large number of structural metals, including steels and aluminums, showed that the various cyclic phenomena in the uniaxial state of stress could be characterized in terms of a cyclic history dependent yield strength. The hysteresis stress-strain curves under cyclic conditions differ only in the lengths of their linear (elastic) parts, whereas their nonlinear portions remain virtually unchanged in shape. Therefore, under multi-axial stress states, these cyclic phenomena could be characterized by a combined isotropic-kinematic hardening model in which isotropic hardening is cyclic history dependent.

For the present formulation, Mroz's plasticity model of hypersurfaces is adopted. These hypersurfaces are assumed to be of von Mises type. The kinematic hardening rule, which stipulates that the hypersurfaces consecutively contact and push each other without intersecting, is retained with a slight modification. In order to model cyclic history dependent isotropic hardening, a field of isotropic hardening moduli, in addition to a field of plastic tangent moduli, is introduced. Each hypersurface is assigned an initial yield strength increment and a saturation yield strength increment (corresponding to history independent state of saturation exhibited by materials). These yield strength increments are obtained from a series of constant strain amplitude tests. In an initial plastic strain excursion to an hypersurface in the stress space, all the hypersurfaces are expanded or contracted by an amount given by the initial yield strength increment of that surface. During subsequent plastic strain excursions, expansion or contraction of the hypersurfaces is governed by the difference between the current yield strength increment and saturation yield strength increment. The advantage of describing isotropic hardening by this approach is that it accounts for the effects of the direction of plastic loading, previous loading history and current strain range on subsequent cyclic hardening (or softening) and saturation response.

The plasticity model developed in this paper is shown to closely simulate the several uniaxial cyclic phenomena of different structural metals exhibiting either cyclic hardening or softening. Experimental data are being sought to test the predictive capability of this model under multi-axial loading conditions. Two important contributions of this paper are: (1) a new and realistic approach of modeling cyclic history dependent material phenomena; and (2) a simple method of obtaining the required material parameters from a few cyclic uniaxial tests. An algorithm for using this formulation in structural analysis is also outlined.