

A NUMERICAL SCHEME FOR TREATING STRAIN-RATE-DEPENDENT PLASTICITY IN PIECE-WISE-LINEAR INCREMENTAL ANALYSIS

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SUMMARY

In the implementation of inelastic analysis procedures within the framework of the finite element method, most formulations start from a common point of partitioning the strain tensor into elastic, plastic and creep components. While this treatment may appear to be phenomenologically artificial, it provides a convenient analytical device for using material data that is usually available in this partitioned form. Furthermore, this practice is consistent with well established analytical theories in creep and plasticity. The associated computational procedure for the plasticity problem generally leads to the incremental tangent stiffness formulation or, alternatively, the initial-strain procedure; the former being the more popular approach. However, the creep problem continues to be treated, with a few exceptions, as an initial strain problem which characteristically suffers from time-step size limitation. The implementation of one procedure or the other in finite element programs has been extensively investigated in the literature and is not the subject of this paper. Rather, we restrict attention to some of the difficulties injected into these numerical procedures by material phenomena and the effects of material property characteristics on the numerical behavior of the problem.

In particular, we consider the computational problem associated with the strain-rate dependence of the yield surface, where the distinct partitioning mentioned above may not be possible in the general case. In this area a number of numerical difficulties have been encountered which become acute in two special situations: the first is in the elastic-plastic transition step and the second is in the purely plastic regime where large tangent modulus variations occur. As a familiar to most workers in this area, these two situations have always required special attention even without the added complication of the strain-rate dependence of the yield surface.

The analytical device of treating the yield surface as strain-rate dependent is an attempt to bridge the gap between the creep deformations which characterize slow plastic flow and the so-called instantaneous plasticity. Assuming the existence of a strain-rate dependent plastic potential, valid over the entire strain-rate range, it is reasonable to expect that a single associated flow rule, common to both the plastic and the creep strains, can be postulated. In this manner, the gap can be bridged between the high strain-rate behavior where the classical plasticity formulation applies and the slow strain-rate response where creep formulation usually governs. Cast in this framework, the analytical problem becomes tractable. However, the numerical implementation of this scheme is difficult and often leads to oscillatory behavior. This is particularly true in the elastic-plastic transition step where the yield surface depends continuously on the instantaneous rate of straining and is changing simultaneously with the changing stresses. Under these conditions, a relatively slow strain rate during loading from an elastic state to a plastic state shortens the path to the yield surface, which may cause the stress increment to become large in comparison with the yield stress and thus cause instability or oscillation. On the other hand, a relatively fast strain rate during a loading step from a plastic state results in a stress increase, which can either be a state of loading if the yield surface expands at a slower rate than the rate of stress increase or a state of unloading if the reverse is true. It is easy to see, therefore, that various combinations of loading or unloading with slow or fast strain rates can lead to complex numerical algorithms in the general case. Numerical remedies for these difficulties will be presented in this paper and their effectiveness will be examined through several examples.