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AN ALTERNATIVE APPROACH TO NON-PROPORTIONAL LOADING IN SEQUENTIALLY LINEAR ANALYSIS (SLA) & ITS EXTENSION TO 3-D STRESS SITUATIONS

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Sequentially linear analysis (SLA) [1], a non-incremental (total) approach towards finite element simulation of quasi-brittle materials, has in the past few years been extended to non-proportional loading situations which are closer to real life loading conditions. The process of finding the critical load multiplier and the integration point per linear analysis was addressed using the superposition of the global stresses and subsequently using the principal stress theory as the failure criterion in a smeared fixed-crack framework. However, the process of damage propagation and localization is a dynamic one, despite the simulation being quasi-static. The need for a redistribution strategy to address this dynamic phenomenon in a quasi-static set-up and the topic of non-proportional loading in SLA in general, have been well documented in literature [2][3]. This work provides an overview on the different strategies used thus far, their applications to elucidate the inherent differences and the applicability of one of the approaches, the constrained maximization analogy [4], to continuum problems in the Finite element method.

Furthermore, a new approach for non-proportional loading in SLA, which would enable 3-D simulations, is introduced. The existing strategies rely on a closed form solution for the critical load multiplier while in 3-D stress states it is cumbersome to follow the same approach. The new approach reformulates the non-proportional loading case as another constrained optimization problem which is referred to as Sequentially-linear theta-based non-proportional loading (SLTHNP) approach. Instead of finding the principal planes from the closed form solution, the critical plane, where the normal stresses due to the scaled combination of two non-proportional loads is equal to the allowable strength, is searched for. In plane stress situations, the scaling factor λ is expressed as a function of θ, the inclination of an arbitrary plane to the reference coordinate system, and a one dimensional (θ) optimization of λ is done to determine the principal plane, the resulting fixed crack coordinate system and consequently the critical load multiplier. SLTHNP has been illustrated to match up to the closed form solution, obtained previously based on the principal stress theory, using single element tests and a quasi-static test pushover test on a masonry shear wall [5]. This concept has now been extended for the 3-D stress situations in this contribution, where the optimization problem becomes two-dimensional, with respect to l and m (two-directional cosines) and yields the 3-D fixed crack system and the critical load multiplier. Validation studies on experimental benchmarks of RC slab tested in shear [6][7], characteristic of 3D cracking, are presented with comparisons of force-displacement relation and crack patterns.

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