Damage plastic model for concrete failure under impulsive loadings

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ABSTRACT

This paper describes a constitutive law for concrete under impulsive loadings such as impacts or explosions. This is an isotropic damage plastic model inspired by [1]. The effective stresses (stresses of the undamaged material) are calculated with a plastic update. Concrete softening is modelled via a damage formulation in which the initial damage threshold surface is identical to the shear failure surface and damage accumulates during plastic flow until concrete is fully damaged. This kind of concrete model is widely used because plasticity and damage are simply coupled which mathematically leads to a well posed problem. Furthermore, calibration procedure of parameters is easier to deal with. The model has been introduced in EUROPLEXUS, a general finite element explicit code for fast transient analysis.

The shear failure surface is a function of the three stress invariants and has been calibrated in terms of the uniaxial strengths in compression f'_c and intension f'_t and a third point belonging to the compression meridian. A cap model is used to close the yield surface at the point of equitriaxial compression. This surface is smooth and convex in stress space except for the vertex located at the point of equitriaxial extension. The cap is used to model compaction and concrete hardening. The cap surface moves toward triaxial compression as concrete hardens according to the pressure-volumetric strain curves. Non-associated plasticity is used to reduce dilation after the yield surface is engaged.

Damage is driven by the maximal principal total strain when stress triaxiality is positive (damage is called brittle) or by a strain-based energy when stress triaxiality is less than -1 (damage is called ductile). A continuous formulation is used between these two boundaries. Distinction between brittle and ductile damages is useful to represent stiffness recovery with crack closure in an approximate way. Brittle damage drops progressively to zero when the triaxiality becomes negative and the damage is progressively recovered when the triaxiality becomes positive again. To mitigate mesh size sensitivity associated with strain softening, the Hilleborg method is used to maintain constant fracture energy regardless of element size. Element erosion can be used to delete fully damaged elements.

Strain rate effect must be introduced to deal with impulsive loadings. For this purpose, plasticity is replaced by viscoplasticity following Simo's formulation which allows stresses to lie outside the yield surface. Furthermore, damage initiation is delayed and fracture energy is modified in a coherent way. The calibration of the formulation is based on Dynamic Increase Factor data.

The model has been verified at the finite element level with numerous loadings. Then, it has been verified at the specimen level on basic tests: Brazilian test and multi-axial compressive tests. Finally, it has been validated upon impact tests against reinforced beams and slabs [2]. Maximum and residual deflections of members are well reproduced so as impact force time histories. Damage patterns reproduce cracks satisfactorily. However, post-pic oscillations are not properly captured and need an extra work for trying to obtain a better evaluation of shock induced vibrations.

REFERENCES

[1] Y. Murray, *Users' manual for LS-DYNA Concrete Material Model 159"*, Publication Federal Highway Administration FHWA-HRT-05-062, USA, (2007).

[2] Improving Robustness Assessment Methodologies For Structures Impacted by Missiles (IRIS_2012), Final report, NEA/CSNI/R(2014)5-ADD1 (2014).