Continuous-discontinuous modelling of quasi-brittle failure

Motivation

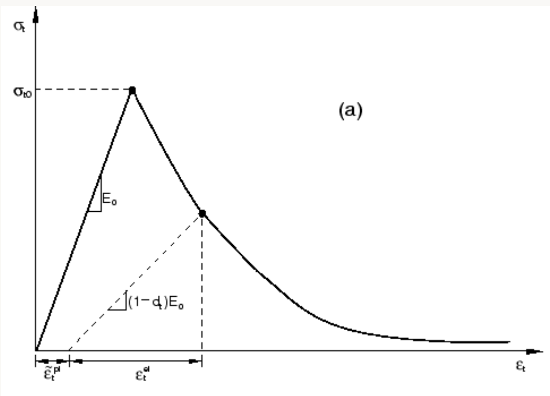
- In some situations cracks have to be explicitly represented. This works aims the creation of a combined method using continuous and discontinuous models to achieve this representation.

Fracture "failure" or Fracture "success"?

- Failure it is in general a word that is given negative connotation and used to indicate a situation where rupture occurs in a material, i.e.:
  - Concrete structure due to an earthquake.
  - Car structure due to a crash event.
- However, there are some applications were fracture means success:
  - Rupture of thin aluminum sheets used for packaging.
  - Sheet metal part cut in a manufacturing process.

Quasi-brittle materials: definition and examples

- Brittle materials are those that exhibit an elastic behaviour up to a certain point and afterwards suddenly experience softening. The softening is controlled by the damaged tangent modulus, i.e. 1D behaviour (in picture below):



Ingredients list for a continuous-discontinuous model of quasi brittle material

- A continuous model: Gradient damage model based on non-local displacements
  - The equivalent strain at a point x does not only depend only on what happens in x but also in its neighborhood. Thus, the non local equivalent strain is introduced:

$$\tilde{Y}(\mathbf{x}) = \int_V \alpha(\mathbf{x},\mathbf{z}) Y(\mathbf{z}) d\mathbf{z}$$

$$\alpha(\mathbf{x},\mathbf{z}) = exp\left[-(2\|\mathbf{x}-\mathbf{z}\|/)^2\right]$$

$\tilde{Y}$is the equivalent strain
$\alpha(\mathbf{x},\mathbf{z})$ is the weighting function
V is a spherical domain surrounding x
z is a coordinate within this surrounding

  - $\tilde{Y}$ is the solution of a diffusion-reaction PDE:

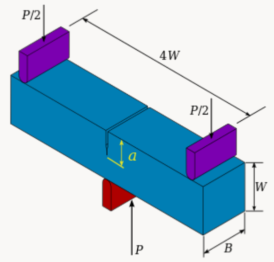
$$\tilde{Y} - l^2\nabla(\tilde{Y})^2 = Y$$
$$\nabla \cdot n = 0 \text{ (Homogeneous Neumann bc)}$$

  - The stated problem is a two field problem, the strain field it is "smoothed" and the solution causes mesh insensitivity. The damaged tangent modulus is now driven by two strain fields, local and non-local or "smoothed" field
- A Criterion for model switching when a crack takes place:
  - Then there is a switch to discontinuous model based of X-FEM enrichment when:

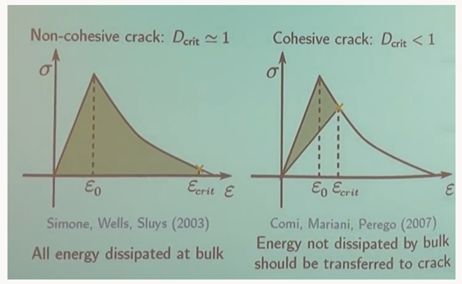
$$D = Dcritical$$

And more ingredients...

- A crack tracking algorithm to follow the crack propagation
  - Mechanical approaches are: 1) Path perpendicular to maximum non-local principal strain 2) In the direction of maximum accumulation of non-local damage
  - In this work we propose a geometrical approach: the crack turns out to be "in the middle" of the damaged zone.



- An energy transfer strategy
  - With crack explicit modelling it is possible to achieve sames levels of energy dissipation that those obtained by continuous models.
  - The energy not dissipated by the bulk has to be transferred to the crack.



Conclusion

Continuous-discontinuous models with gradient damage model based on non-local displacements are appropriate to model explicitly propagation of cracks. In future work complex crack patters have to be studied.

Antonio Rodríguez-Ferran
Elena Tamayo-Mas, Jordi Feliu-Fabà, Héctor Mestre, Angelo Simone (TU Delft)
Universitat Politècnica de catalunya (UPC), Laboratori de Càlcul Numèric