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ON THE EXPLICIT SIMULATION OF CONCRETE CRACKING USING ONE ENRICHED FINITE ELEMENT METHOD

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Summary. *A lot of methods were developed in the past for the computation of concrete cracking. Combining these mostly kinematical enriched finite element methods with a geometrical model is straightforward when dealing with load reversal and cyclic load cases. The Strong Discontinuity Approach is applied to model the localisations. Once these are fully developed within a finite element formulation, the element interfaces will be detached and a contact formulation might be needed to model the post-crack states.*

1 INTRODUCTION

In order to model cracking concrete in a realistic way, several models were developed in recent years. Either the cracks are explicitly represented in the geometry model or implicitly treated in the numerical model of the structure. In case of a load reversal, which means that the pseudo fractured parts can come into contact again, non-geometrical approaches like the XFEM, PUFEM or the Strong Discontinuity Approach (SDA) reach their limits. The dynamic fracture occurs during very short time periods, therefore integration methods should be based on explicit time discretization schemes.

Various methods for a non-geometrical representation of the failure zone are topics of today research[1]. All methods enrich the standard finite element galerkin approach with additional degrees of freedom, but differ basically in their kind of support. The goal is a model to simulate the behaviour until the fracture occurs as well as the post critical processes.

2 STRONG DISCONTINUITY APPROACH

The method of Enhanced Assumed Strains (or common known as SDA)[2] is an adequate choice when using explicit time integration schemes since the formulation has local support. It can take failure processes into account which occur in the element.

The failure zone can be subdivided into three different zones with distinct behaviour. In the diffuse failure zone the initiation of the dissipative process takes place, leading to an increase and concentration of the strains. The weak discontinuity describes the concentration of the strains which approximates the discontinuous strain field (up to a localisation) by a continuous displacement field.

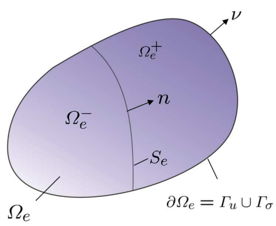

Figure 1: Standard model problem.

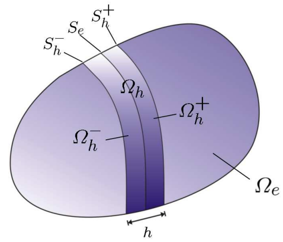

Figure 2: Model problem with strong discontinuities.

For continuous displacements or furthermore weak discontinuities (see figure 1), the standard formulation of the weak problem yields

$$\int_{\Omega} \varrho \boldsymbol{N}^T \boldsymbol{N} \, d\Omega \; \ddot{\mathbf{u}}^h + \int_{\Omega} \boldsymbol{B}^T : \boldsymbol{\sigma}^h \, d\Omega = \boldsymbol{f}_{ext}. \tag{1}$$

With respect to the existence of a discontinuous displacement (Figure 2) field, the weak formulation has to be locally enforced for the continuity of the traction vector across the discontinuity surface. The corresponding weak form is

$$\int_{\Omega_e} \boldsymbol{G}_e^{*T} \cdot \boldsymbol{\sigma}^h \, d\Omega_e = \mathbf{0}. \tag{2}$$

The resulting jump function can be condensed at element level[1]. Hence this method is an appropriate choice for explicit time integration schemes

$$\boldsymbol{\alpha}_e = -(\boldsymbol{G}_e^{*T} \mathbb{C} \boldsymbol{G}_e)^{-1} \cdot \boldsymbol{G}_e^{*T} \hat{\boldsymbol{\sigma}}^h. \tag{3}$$

By considerating the displacement jump $\boldsymbol{\alpha}_e$, the enhanced assumed stress follows directly for an enriched finite element by addition of the galerkin stresses $\hat{\boldsymbol{\sigma}}^h$ and the stresses of the discontinuity $\tilde{\boldsymbol{\sigma}}^h$, respectively

$$\boldsymbol{\sigma}^h(\boldsymbol{x}, t) = \hat{\boldsymbol{\sigma}}^h(\boldsymbol{x}, t) + \tilde{\boldsymbol{\sigma}}^h(\boldsymbol{x}, t, \boldsymbol{\alpha}_e, \hat{\boldsymbol{\sigma}}^h). \tag{4}$$

The above mentioned formulation can be used to model the behaviour, until a characteristic internal element variable which describes the failure process is fully developed. One obvious alternative is the choice of a localisation bandwidth $h(\boldsymbol{x}, t)$. When this variable reaches a limit value, the modeling is switched from the kinematical approach to a geometrical one.

3 GEOMETRICAL APPROACH

The elements which are fully localised have to be divided in localization direction resulting of the acoustic tensors analysis. This fracture surface is a coproduct of the non-geometrical computation and can be calculated in a closed manner[4]. In order to pass a contact analysis of the arised surfaces a geometrical description of these surfaces are needed.

For an efficient and stable contact search algorithm, sufficient smothness of the surface is necessary. The Mesh adaptation which is related to the introduction of the fracture surface is quiet simple to implement in two dimensions (figure 3). Assuming that the crack arrises at one surface of the primarily body, the crack propagation can be modeled as shown. Otherwise a small variation of the initial crack opening is used.

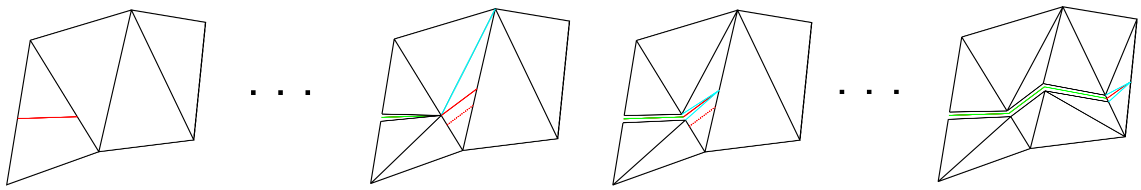

Figure 3: Geometrical crack representation in 2D.

When carrying this method forward to the three dimensions case some obstacles have to overcome. Figures 4 and 5 show an example for mesh adaptation. Assuming the availability of adaptive mesh refinement in the finite element code, this approach is relatively easy to implement and provides proper surfaces for the subsequent contact analysis. Features like crack reunion and crack dividing can be realized within this crack propagation model.

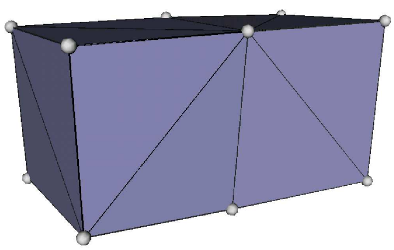

Figure 4: 3D unfractured body.

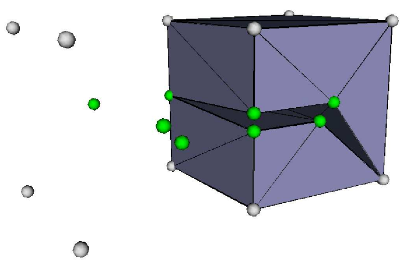

Figure 5: 3D fractured body.

With these described approach it is possible to model the behaviour of concrete structures under cyclic load cases while considering the existence of fracture surfaces. This method is based on a well established method for the modeling of strong discontinuities until the failure process is complete. Afterwards a geometrical representation is taken into account to model the fracture surfaces and to set the basis for a contact computation of the fractured parts after a load reversal.

REFERENCES

[1] M. Jirasek. Comparative study on finite elements with embedded discontinuities. *Comp. Meth. in Appl. Mech. and Engng.*, **188**, 307–330, 2000.

[2] J. Oliver. Continuum modeling of strong discontinuities in solid mechanics using damage models. *Computational Mechanics*, **17**, 49–61, 1995.

[3] A. Pandolfi and M. Ortiz. An Efficient adaptive procedure for three-dimensional fragmentation simulations. *Journal of Engineering with Computers*, 2001.

[4] J. Oliver and A.E. Huespe. Theoretical and computational issues in modeling material failure in strong discontinuity scenarios. *Comp. Meth. in Appl. Mech. and Engng.*, **193**, 2987–3014, 2004.