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MODELING OF SURFACE WEAR BY THE PARTICLE FINITE ELEMENT METHOD. APPLICATION TO TUNNELING PROCESSES

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Summary. This work introduces the advances in the Particle Finite Element Method (PFEM) for the modeling of contact and wear between solid materials. The PFEM is an original conjunction of solution strategies. The method has its foundation on the Lagrangian description of the motion of a continuum medium built from a set of particles with known physical properties. The capabilities of the PFEM makes it very suitable for modeling rapid changing boundaries and moving free surfaces.

The method uses a remeshing process combined with the *Alpha-shape* concept to detect the contacting surface and a finite element mesh for the mechanical computation. A new treatment of contact has been developed for the PFEM scheme, the *Contact Constraint Method*. When contacting forces are computed, an *Archard* law is used for the wear calculation. The material parameters govern the coupling of contact and wear between the solid domains.

The method has been applied to model tunneling processes. Preliminary results show that the PFEM is a very suitable tool for the simulation of wear. Also for the treatment of several other processes related in the common interaction between solid domains.

1 INTRODUCTION

The most common application of the PFEM can be found in the field of computational fluid dynamics (CFD) [3] [4]. The good capabilities of the method for describing free surfaces was the motivation to apply the method to solid mechanics. Especially for the detection of the domain boundaries in *Contact Mechanics*. A first application of the PFEM in solid mechanics can be found in [6].

The PFEM uses all the previous background of the standard Finite Element Method (FEM) and introduces new tools to increase the geometrical adaptability to the model via automatic remeshing. The description of the continuum is based on particles, which usually correspond to the nodes of the finite element mesh. From a cloud of particles and by means of a Delaunay tessellation [1] a mesh can be generated in the complete convex hull. The *Alpha-shapes* assigned to the particle description are used to recover the solid contour and for the geometrical detection of the contact between multiple domains. The *Continuum Constraint Method* is developed for the treatment of contact conforming the PFEM characteristics.

After computing contact forces a volume loss rate can be applied to quantify the wear produced in the contact surfaces. The geometry of the boundary is readapted concurrently with the changes of these contact surfaces. Large geometrical changes are especially remarkable in tunneling processes where wear plays an important role.

2 GEOMETRIC CONTACT DETECTION

The geometrical detection of contact is a complex problem in computational contact mechanics. The geometric search is especially complex when the contact of more than two bodies has to be considered. That can happen when the problem is such that the solids can break, and hence during the solution process, several discrete elements are originated from the initial set up. This is common in excavation problems. The search for an active set of contact constraints is not trivial in this case.

In the PFEM the contact detection is easily performed by means of a remeshing process. From the particle description the proper *Alpha-shape* is used for the mesh creation. An interface mesh is generated between the multiple domains when they are coming into contact. That is shown in Figure 1

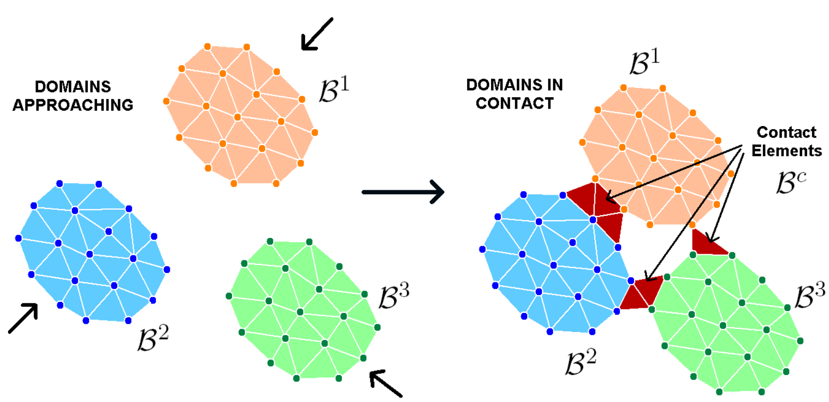

Figure 1: Geometric contact detection in the PFEM.

3 CONTINUUM CONSTRAINT METHOD

For the PFEM a new formulation for the contact contribution has been developed. It is based in the interface mesh created in the contact detection. The contact constraint for the present formulation is founded on the potential of a fictitious continuum domain that works between the contacting bodies $\mathcal{B}^c$. When the constraint is active on the body surfaces $\partial\mathcal{B}^c$ the continuum contact constraint can be written as:

$$C_c^{CC} = \int_{\boldsymbol{\varphi}(\mathcal{B}^c)} (\mathbb{P}\,\boldsymbol{\sigma}_c + \boldsymbol{\kappa}_c) \cdot \nabla^S \boldsymbol{\eta}_c \tag{1}$$

with the projection tensor $\mathbb{P} = \bar{\mathbf{n}}^1 \otimes \bar{\mathbf{n}}^1$ and $\bar{\mathbf{n}}^1$ being the normal for the contact surface at the minimum distance point. $\boldsymbol{\kappa}_c$ is denoted the tangential stress tensor for contact. Using a classical frictional law, e.g. *Coulomb* law, $\boldsymbol{\kappa}_c$ can be written as:

$$\boldsymbol{\kappa}_c = -\mu\; \mathbb{T}\,\boldsymbol{\sigma}_c \tag{2}$$

where μ is the is the sliding friction coefficient and $\mathbb{T} = \bar{\mathbf{t}}^1 \otimes \bar{\mathbf{n}}^1$, being $\bar{\mathbf{n}}^1$ and $\bar{\mathbf{t}}^1$ the normal and the tangent vectors defined on the contact surface.

4 CONTACT MODEL WITH WEAR

Wear is predicted by computing the material that is dug due to the contact interaction. The surface properties of the interacting materials control the wear occurring during the frictional contact (see Figure 2). When a steady state position in the wear mechanisms is reached the wear rate is described by a linear Archard-type equation [2] as:

$$V_{wear} = k_{abr} \frac{F_N\, g_T}{H} \tag{3}$$

where F_N are the contact normal forces, $g_T := x$ is the relative sliding distance and k_{abr} is the abrasive wear coefficient, that physically represents the average tangent of the roughness angle divided by π.

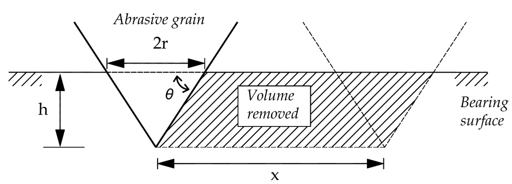

Figure 2: A simplified abrasive wear model showing how a cone removes material from a surface

5 EXAMPLES

Several examples for the normal and frictional contact calibration has been made. Figure 3 shows a numerical test for friction characterization between a cube and a foundation.

The method is applied to model tunneling processes. A large number of 2D and 3D excavation and rock cutting models have been computed. They are presented in order to show the efficiency of the method for modeling wear in these type of problems. Figure 4 shows an example for a TBM Disc model.

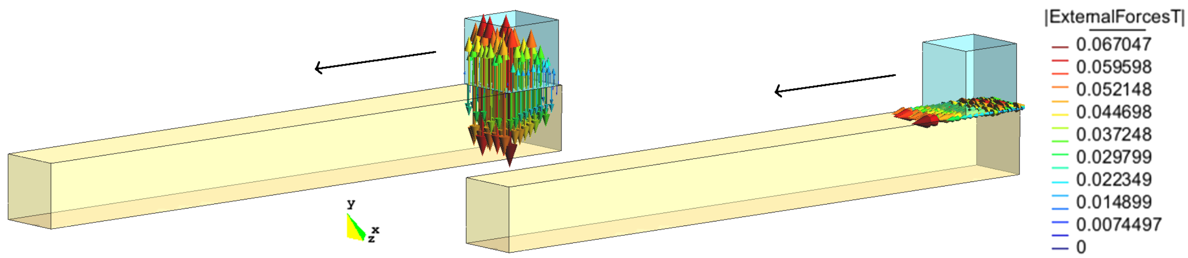

Figure 3: Numerical calibration of normal and frictional contact in 3D.

The impacting forces are depicted with the resulting accelerations on the disc and in the geomaterial. Wear is properly quantified in contact zones.

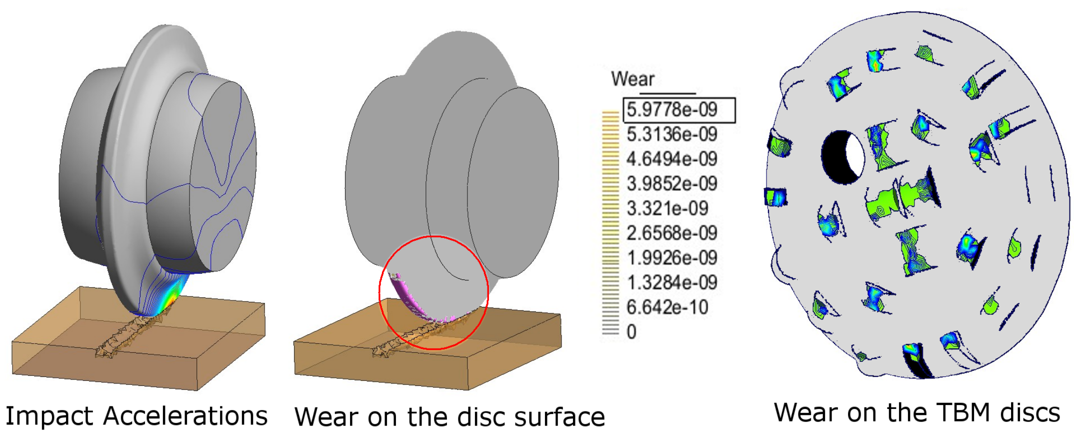

Figure 4: Wear on a TBM hear and on one of its cutting discs.

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