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OPEN SOURCE FEM-DEM COUPLING

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Abstract: *Finite element method (FEM) and discrete element method (DEM) are leading strategies for numerical solution of engineering problems of solid phase. Both are applicable in different situations and sometimes can be beneficially coupled. Coupling of two free open source programs (finite element code OOFEM and discrete element code YADE, both with C++ core and Python user interface) is presented. Some of the basic coupling strategies (surface coupling, volume coupling, multi-scale approach and contact analysis) are explained on patch tests and simple simulations.*

Keywords: ***FEM, DEM, coupling, Python scripting, open source***

1. Introduction

For different engineering areas there are different numerical methods used. In solid phase mechanics, the leading methods are the finite element method (FEM) and the discrete (distinct) element method (DEM).

There are countless software programs for both FEM and DEM. Some of them are commercial (usually) without possibility to change the code and adjust the behavior to our requirements (combination with another software for instance). However, there exist programs with open source code, which the user can modify, possibly for coupling with another programs. In the present article, coupling of FEM code OOFEM and DEM code YADE is presented. Both programs have the core written in C++ (providing efficient execution of time consuming routines), user interface written in Python (modern dynamic object oriented scripting language, providing easy to use scripting while preserving the C++ efficiency) and extensible object oriented architecture allowing independent implementation of new features - new material model or new particle shapes for instance.

Basic principles of different coupling strategies are explained , implementation issues are covered and examples together with controlling Python scripts are provided.

2. Theory, implementation, examples

The basic principles of the most popular FEM/DEM coupling strategies (surface, volume, multiscale and contact coupling) are presented, together with specific examples and corresponding Python scripts. All methods can be arbitrarily combined with each other or with different methods/programs (which uses Python user interface).

Surface coupling solves two non-overlapping domains, one modeled by FEM and the other by DEM. If a contact between a finite element and a DEM particle is detected, the new repulsive force becomes acting on the DEM particle (causing its acceleration) and on the FEM element (processed as a load boundary condition).

Volume coupling solves two overlapping (FEM and DEM) domains. The transition zone between FEM and DEM (where both methods directly influence each other) can be modeled either with ”hanging nodes” or with ”Arlequin” method.

Multiscale coupling (in presented form) solves macroscale problem (displacement field) with FEM. The strain is transfered to micro scale RVE modeled by DEM, boundary value problem is solved and

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stress tensor and stiffness tensor are transfered back to the macro-scale problem. As stiffness is evaluated on DEM scale, we do not need any explicit expression of the material law on the FEM scale.

Contact coupling considers the material on the large scale to be of a particulate nature and is modeled by particles using DEM. Each such particle is further modeled by FEM. This strategy can be actually considered as full FEM, only the contact detection is ”borrowed” from the DEM program.

The current implementation serves only for testing of the methods and functionality. When the testing is finished, the functionality will be implemented into the **MuPIF** prject to enable coupling with other programs or other physical models (heat transfer for instance).

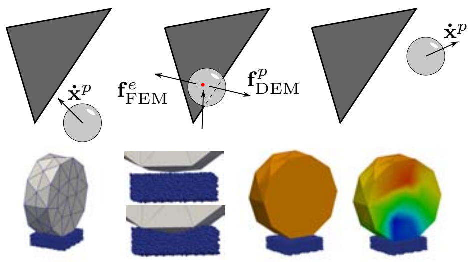

Fig. 1: Surface coupling

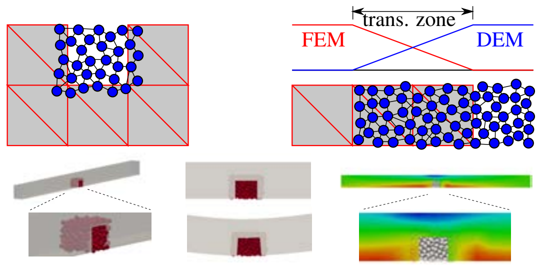

Fig. 2: Volume coupling

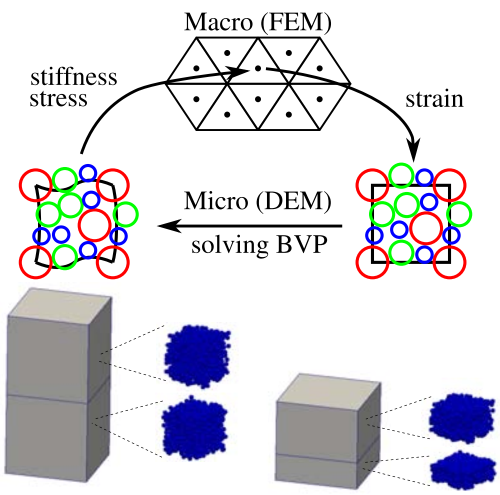

Fig. 3: Multiscale coupling

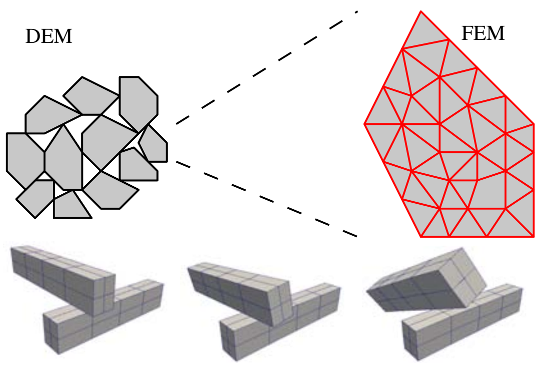

Fig. 4: Contact coupling

3. Conclusions

The simplicity of creating, modifying and running such simulations and extensibility of the used programs (due to the open source character of the code) makes this approach attractive for a variety of engineering problems.

Future work on this topic will address (among others) second order DEM homogenization, adjustment of DEM periodic boundary conditions for arbitrary localization analysis, implementation and testing of Arlequin volume coupling method, implementation of contact detection algorithms of FEM element shaped particles and implementation of testing interface into **MuPIF** framework.

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