Ph.D. dissertation
Extended mortar method for contact and mesh-tying applications

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Abstract

In this work we develop a set of methods to handle tying and contact problems along real and virtual (embedded) surfaces in the framework of the finite element method. The first objective is to elaborate an efficient and fully consistent three-dimensional mortar formulation using the monolithic augmented Lagrangian method (ALM) to treat frictional contact problems (see Fig. 1). Various aspects of the numerical treatment of contact are discussed: detection, discretization, accurate evaluation of mortar integrals (projections, clipping, triangulation), the parallelization on distributed memory architectures and optimization of convergence for problems involving both contact and material non-linearities. With mortar methods being drawn from the domain decomposition methods, the mesh tying problems for the class on non-matching interfaces is also presented.

A new two-dimensional MorteX framework, which combines features of the extended finite element method (X-FEM) and the classical mortar methods is elaborated. Within this framework, mesh tying between overlapping domains and contact between embedded (virtual) boundaries can be treated. However, in this setting, severe manifestation of mesh locking phenomenon can take place under specific problem settings both for tying and contact. Stabilization techniques such as automatic triangulation of blending elements and coarse-grained Lagrange multiplier spaces are proposed to overcome these adverse effects (see Fig. 2). In addition, the coarse graining of Lagrange multipliers was proven to be useful for classical mortar methods, which is illustrated with relevant numerical examples.

The MorteX framework is used to treat frictional wear problems. Within this framework the contact surface evolution as a result of material removal due to wear is modeled as an evolving virtual surface. Use of MorteX method circumvents the need for complex remeshing techniques to account for contact surface evolution. The proposed methods are developed and implemented in the in-house finite element suite Z-set. Numerous numerical examples are considered to validate the implementation and demonstrate the robustness, performance and accuracy of the proposed methods.

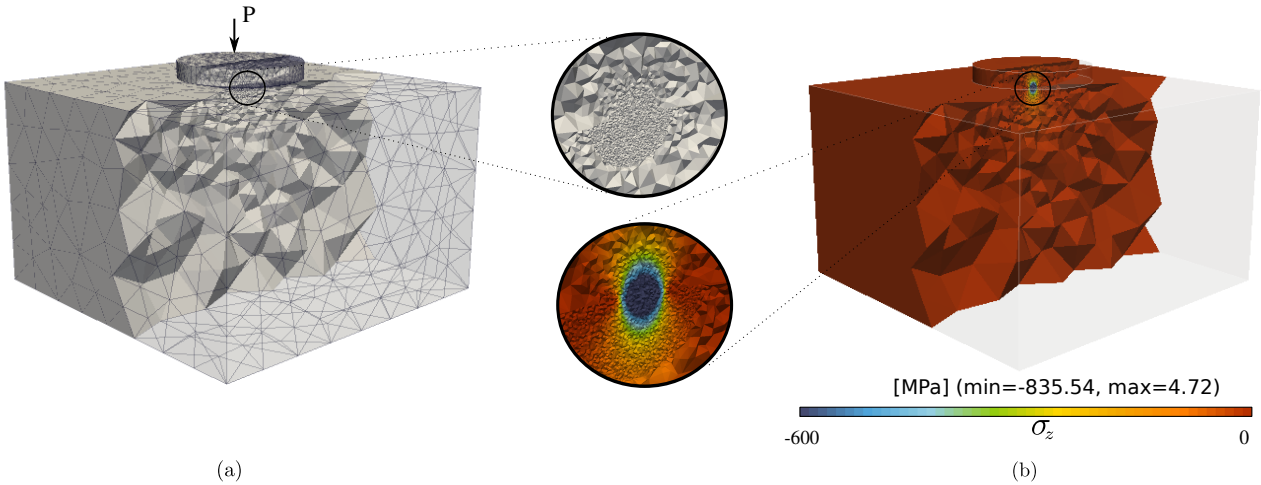

Figure 1: Sphere on flat contact set-up: (a) FE discretization used for the analysis, (b) contour plot of the vertical stress component σ_z, a zoom in the vicinity of the contact zone is also shown.

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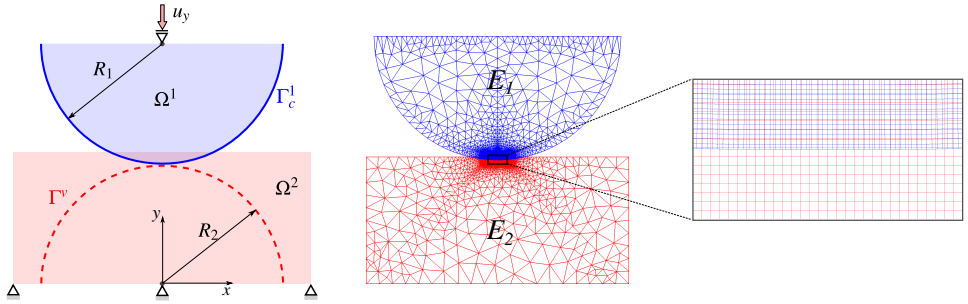
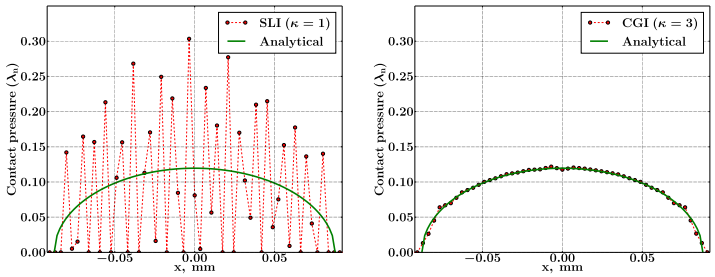


(a)



(b)

Figure 2: (a) Cylinder-on-cylinder contact problem set-up in MorteX framework (the upper solid is much stiffer than the lower one: $E_1/E_2 = 1000$) Γ^v is an embedded surface over which the contact takes place; (b) contact pressure distribution: spurious oscillations obtained with the standard mortar method (SLI) are removed by using the coarse grained (CGI) Lagrange spaces.

Articles

- B.R. Akula, V.A. Yastrebov, J. Vignollet, G. Cailletaud, "Domain tying across virtual interfaces: coupling X-FEM with the Mortar method", in proceedings of **13^{e} Colloque National en Calcul des Structures**, Giens, France, 15-19 May 2017.
- B.R. Akula, J. Vignollet, V.A. Yastrebov, "Stabilized mortar methods for embedded interfaces", in final stage of preparation.
- B.R. Akula, J. Vignollet, V.A. Yastrebov, "Contact along real and virtual interfaces: coupling the X-FEM with the Mortar method", in final stage of preparation.

Conferences

- B.R. Akula, V.A. Yastrebov, J. Vignollet. "Contact Along Virtual Interfaces for Wear Simulation: Embedded Mesh with Stabilized Mortar Discretization", at **13th World Congress in Computational Mechanics**, New York, USA, 22-27 July 2018 (oral presentation by V.A. Yastrebov).
- B.R. Akula, V.A. Yastrebov, J. Vignollet. "Frictional contact and wear along virtual interfaces", at **6th European Conference on Computational Mechanics (Solids, Structures and Coupled Problems)**, Glasgow, Scotland, 11-15 June 2018 (oral presentation).
- B.R. Akula, V.A. Yastrebov, J. Vignollet. "Frictional contact and wear along virtual interfaces", at **Contact Mechanics International Symposium**, Sanctuary of Oropa, Biella, Italy, 16-18 May 2018 (oral presentation).
- B.R. Akula, V.A. Yastrebov, J. Vignollet. "Contact along virtual interfaces: coupling the X-FEM with the mortar discretization", at **GACM Colloquium on Computational Mechanics**, Stuttgart, Germany, 11-13 October 2017 (keynote lecture given by V.A. Yastrebov).
- B.R. Akula, V.A. Yastrebov, J. Vignollet. "Frictional Contact and Wear Along Virtual Interfaces: Coupling the Mortar Method with the X-FEM", at **5th International Conference on Computational Contact Mechanics**, Lecce, Italy, 5-7 July 2017 (oral presentation).