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EXTENDED FINITE ELEMENT MODELING OF LARGE DEFORMATION FRICTIONAL CONTACT

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ABSTRACT

In this paper, the extended finite element method is employed to model discontinuities caused by frictional contact. The method is used in modeling discontinuity within a standard finite element framework. In XFEM technique, the special functions are included in standard FE method to simulate discontinuity without considering the boundary conditions in meshing the domain. The classical finite element approximation is enriched by applying additional terms to simulate the frictional behavior of contact between two bodies. The partition of unity method is applied to discretize the contact area with triangular sub-elements whose Gauss points are used for integration of the domain of elements. In order to construct the integrals on the contact surface, it is necessary to implement the material property matrix of frictional contact at the Gauss points located on contact bond.

The standard FE approximation is enriched with additional functions by using the notion of partition of unity, i.e.

$$\mathbf{u}^h(\boldsymbol{x}) = \sum_i N_i(\boldsymbol{x})\,\mathbf{u}_i + \sum_j N_j(\boldsymbol{x}) f(\boldsymbol{x})\,\mathbf{a}_j \tag{1}$$

where $\mathbf{u}_i$ is the classical nodal displacement, $\mathbf{a}_j$ the nodal degrees of freedom corresponding to the enrichment functions, $f(\boldsymbol{x})$ the enrichment function, and $N(\boldsymbol{x})$ the standard shape function. In modeling contact problems with strong discontinuity on the contact interface, the Heaviside enrichment function is used to model the jump over the interface. The nonlinear XFEM technique proposed by Khoei et al.[1-3] is used to model the large elasto-plastic deformation problems. The tangent stiffness matrix and the external force vector is calculated using the following relations

$$\bar{\mathbf{K}}_{T\,ij} = \begin{bmatrix} \bar{\mathbf{K}}_{ij}^{uu} & \bar{\mathbf{K}}_{ij}^{ua} \\ \bar{\mathbf{K}}_{ij}^{au} & \bar{\mathbf{K}}_{ij}^{aa} \end{bmatrix},\ \mathbf{f}_i = \left\{ \mathbf{f}_i^u \quad \mathbf{f}_i^a \right\}^T \tag{2}$$

$$\bar{\mathbf{K}}_{IJ}^{\alpha\beta} = \int_{\Omega^e} (\bar{\mathbf{B}}_I^\alpha)^T \mathbf{D}_{\mathbf{S}}^{ep}\, \bar{\mathbf{B}}_J^\beta\, d\Omega + \int_{\Omega^e} (\mathbf{G}_I^\alpha)^T \mathbf{M}_{\mathbf{S}}\, \mathbf{G}_J^\beta\, d\Omega \qquad (\alpha,\ \beta = u,\ a) \tag{3}$$

For the elements cut by the contact surface, the standard Gauss quadrature points are insufficient for numerical integration. Thus, it is necessary to modify the element quadrature points to accurately evaluate the contribution to the weak form for both sides of the contact surface. Evaluation of the stiffness matrices for the elements located on contact surface requires linearization of the governing equations for the frictional contact problem. In order to preserve the symmetry of the numerical formulation, the coupling between the normal and tangential stresses at the interface is neglected in the initial formulation and its effect is later brought into the formulation via residual 'pseudo loads'.

Finally, in order to present the capabilities of XFEM technique in modeling of contact problems with large deformation, the rotation of rod inside a plate is simulated, as shown in Figure 1. The stress contour of σ_x is presented in this figure. In Figure 2, a slope is modeled using X-FEM technique.

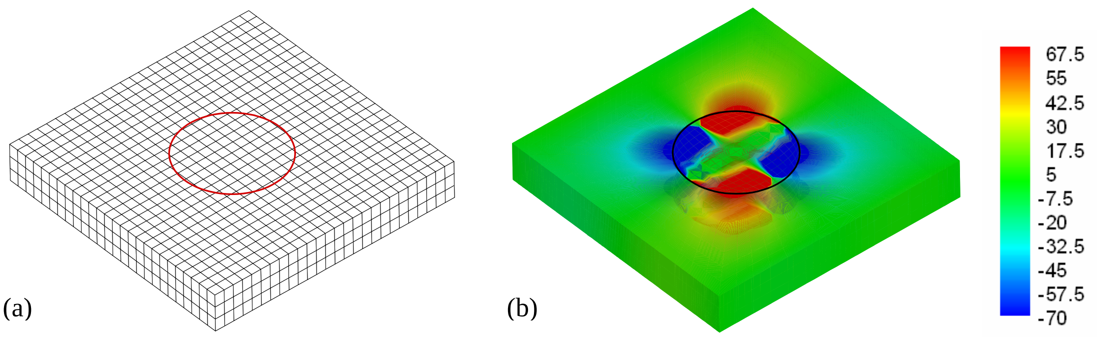

Figure 1. The rotation of rod inside a plate, a) The X-FEM model, b) The stress σ_x contour

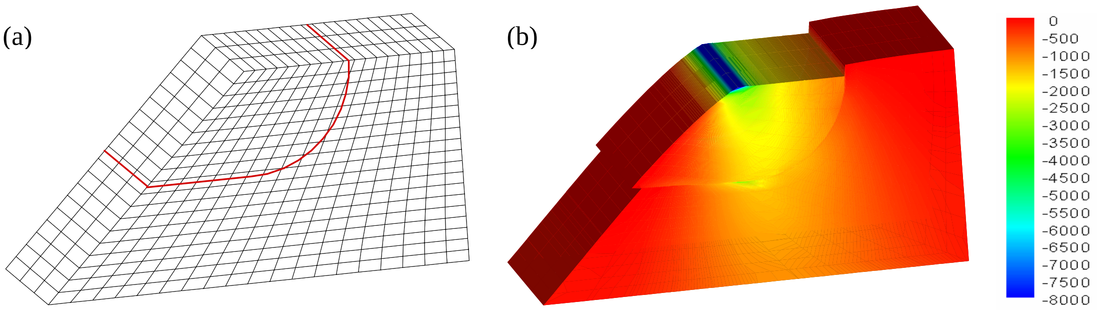

Figure 2. The slope problem, a) The X-FEM model, b) The stress σ_y contour

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