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Generalized Methods For Finite Element Interfaces LDRD Final Report

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Auspices

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Generalized methods for finite element interfaces

Cover Document for the LDRD Final Report: Publications providing detailed descriptions of work are included as attachments.

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Mesh generation is now the main bottleneck in computer-aided analysis. Much of the effort in the production of a complex finite element model is the interfacing of individual parts at part boundaries. When individually meshed parts are to be connected to form a single monolithic part, analysts work very hard to ensure that the meshes conform at the part interfaces (i.e. the nodes match at the common boundary). The process of producing conforming meshes is one of the main difficulties in mesh generation and is intractable and sometimes impossible when connecting meshes composed of different element types (c.f. Figure 1.a). Although standard mesh tying methods are an alternative to producing conforming meshes, it is well known that they cause large errors and are avoided. Consequently, a method that can connect (tie) dissimilar meshes accurately would be an effective tool in mesh production and significantly simplify analyst efforts. Furthermore, dissimilar (non-conforming) meshes are unavoidable when parts are interfaced via contact surfaces (c.f. Figure 2). Despite their common use, contact surfaces still cause serious analysis problems (inaccuracies, code crashing etc.)

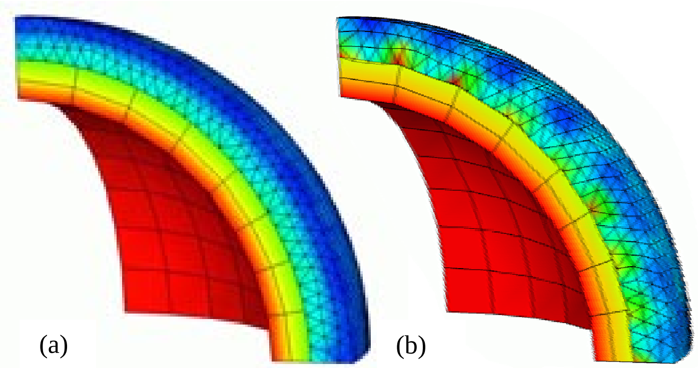

Figure 1.Tied hexahedral-tetrahedral mesh of internally pressurized sphere. (a) Mortar tying produces smooth stresses with stress error at boundary of 1.78%. (b) The standard tying method yields non-smooth stresses with stress error of 220% at boundary.

The goal of this project was to research and develop *robust* and *accurate* methods for interfacing (i.e. tying and contacting) dissimilar meshes. This new technology could save a significant amount of time and money invested in mesh production. For example, a large weapons model takes a month to build and will undergo many revisions over a matter of years. Analysts estimate that an accurate method for tying dissimilar meshes could save 10-25% of their time in meshing over the course of a project. Furthermore, analysts spend a significant amount of time dealing with problems related to contact surfaces; particularly for *implicit* finite element analysis. The new, more robust approach should make analysis with contact surfaces more accurate and more reliable.

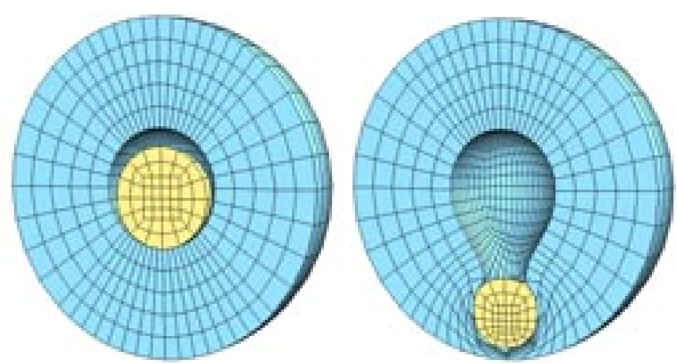

Figure 2. Elastic sphere forced into thick elastic shell. Analysis performed with *implicit* finite element method using mortar contact. Standard contact methods cannot nearly approach this significant amount of deformation with *implicit* finite elements.

The "mortar method" for connecting 2-D, flat interfaces has been extended to connect arbitrary 3-D, curved meshes so that optimal convergence is achieved. In this way, refinement of the dissimilar mesh will have the same asymptotic convergence rate as the conforming mesh, thus dissimilar meshing will not compromise accuracy. This method requires solving surface integrals involving Lagrange multiplier fields for traction and displacement. Such surface integrals are straightforward for 2-D, flat interfaces but complicated for 3-D, curved surfaces. In FY2001, we developed a closest-point projection type algorithm for 3-D surface integrals and used simple Lagrange multiplier fields to demonstrate optimal convergence on 3-D models with curved, tied interfaces [1-3]

In FY2002, we further developed our theory for stability conditions; implemented a dual formulation for the Lagrange multiplier fields, which sped calculation times by a factor of 7 over our previous results [4]; and began work on the mortar method for contact. [5]

In FY03 we worked on a mortar implementation that can connect meshes with different element types (i.e. tetrahedrals and quadratic elements). Now, automatically generated tetrahedral meshes can be accurately interfaced with hexahedral meshes (Figure 1.) Friction was also added to the mortar contact [6]. The new mortar contact provides vastly superior non-linear convergence behavior since it effectively smoothes the behavior near the interface and eliminates the "locking" associated with the standard contact methods. Consequently, contact analyses that failed (crashed) in the past can be successfully analyzed using *implicit* finite elements with our new mortar approach (Figure 2).

Closure

Through this research, we have so far published four refereed journal papers [1],[4-6] and two refereed conference papers [2,3] which are all included as attachments to this cover letter. We also delivered two conference presentations at the World Conference in Computational Mechanics (WCCM) in Vienna Austria in August 2002 and one invited presentation at the US National Conference on Computational Mechanics conference (USNCCM) in Albuquerque New Mexico, July 2003. In fact we are currently are in the process of finishing a paper on the quadratic finite element implementation of the mortar contact method. Here general methods for robustly tying and contacting 20 and 27 node hexahedral elements, 10 tetrahedral elements, 8 node trilinear hexahedral and 4 node linear tetrahedral elements in arbitrarily fashion (e.g. 10 node tetrahedral elements contacting 20 node hexahedral elements etc.) are presented. This capability is unprecedented.

[1] Puso, M.A., T.A. Laursen, Mesh tying on curved interfaces in 3D. 20, (2003) 305-319 Engineering Computations (UCRL-JC-148546)

[2] Puso, M.A., T.A. Laursen, A 3D Contact Smoothing Method, Proceedings of the World Conference in Computational Mechanics, (2003) UCRL-JC-148192

[3] T.A. Laursen, Puso, M.A. and Heinstein, M., Practical Issues Associated with Mortar Projections in Large Deformation Contact/Impact Analysis, Proceedings of the World Conference in Computational Mechanics (2003) (UCRL-JC-148194)

[4] Puso, M.A., A 3D Mortar Method for Solid Mechanics, International Journal for Numerical Methods in Engineering, 59 (2003) 315-336 (UCRL-JC-148546)

[5] Puso, M.A., T.A. Laursen, A Mortar Segment-to-Segment Contact Method for Large Deformation Solid Mechanics, Computer Methods in Applied Mechanics and Engineering, 193 (2004) 601-629 (UCRL-JC-153341).

[6] Puso, M.A., T.A. Laursen, A mortar segment-to-segment frictional contact method for large deformations, Computer Methods in Applied Mechanics and Engineering (to appear), (UCRL-JP-200667).