CAE Based on Polyhedral Finite Elements

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Polyhedral finite element methods (PFEM) are a new class of approximation methods that are largely free of the rules and constraints attending conventional finite element discretizations.Consequently,PFEM meshes can alwaysbegenerated with little or no human intervention, no matter how complex the exterior geometry or internal interfaces between material types.Fully realizing this potential, however, requires some significant advances in computational geometry.Inthis presentation, a new PFEM-based CAE system is described, encompassing solid-modeling, boundary-conditions/loads,auto-meshing,analysis,and visualization modules.The solid-modeling module is based on a ‘‘material-aware’’conception of constructive solid geometry,wherein the geometry and its material constituents are constructed via a user-defined tree of Boolean operations.Atevery step in the solid-modeling process,anexplicit, facetized boundary representation (b-rep) is maintained that is guaranteed to be watertight and topologically correct. Boundary conditions,loads, and material-type designations are then applied to the solid model – no mesh exists yet – using intuitive solid-modeling-like tools.Next comes preparation of the mesh, whichcan consist of polyhedra of general shape.This step proceeds automatically, with the user supplying only directives related to desired mesh density and its spatial distribution. The mesh inherits all BC, loads, and material-type data from the underlying solid model. Analysis and subsequent visualization then proceed in the normal way.

This tightly-integrated geometry-to-analysis workflow relies on a novel ‘‘toleranceaware’’geometric intersection algorithm. Both the Boolean operations in the solidmodeling phase,aswell as the ‘‘sculpting’’operation that produces the final polyhedral mesh, place heavy demands on the resolution of polytope-on-polytope intersections.Intersection resolution is among the most basic of problems in computational geometry,but remains a challenge if arbitrary patterns of near-degeneracy are to be tolerated while guaranteeing topological correctness of the result.

The particular PFEM approximation method used in this work, called the ‘‘partitioned element method,’’ exhibits all of the favorable properties of conventional isoparametric finite elements,while accommodating arbitrary polyhedral element shape (including non-convexity). In its current form, the element formulation resembles a polyhedral generalization of the conventional 8-node hex element, and exhibits comparable solution accuracy and performance on a per-dof basis.Higherorder approximations are possible based on the partitioned element method, though they are so-far unexplored.

Suggested Conference Themes

Innovations in Engineering Analysis and Simulation Technology: innovative approximation methods and evolutionary optimization; driving design improvement and optimization from smart simulations