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Analysis of Shell-like Structures with Boundary Face Method Based on 3D Elasticity

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Accurate and reliable numerical analysis of plate and shell structures has been one of challenging tasks for the computational mechanics[1-2]. The Finite Element method (FEM) has been widely applied in analysis of these structures successfully in most cases. However, pale and shell finite elements are based on various assumptions about geometry, loading, deformation of the concerned structure, therefore, have many limitations in application, such as numerical locking, edge effect and specially the convergence problem. To cope with these problems, the Boundary Element Method (BEM) is used to analyze all types of shell-like structures based on 3D elasticity[2]. Unfortunately, the BEM still uses the standard elements approximation of the geometry, thus the new challenging task of on modeling complicated structures with suitable boundary elements will be faced. Therefore, the applications on 3D thin structural analysis with the BEM are mostly limited to the case of simple geometry.

In this work, the Boundary Face Method (BFM)[3] is employed to analyze arbitrary shell-like structures. As the BEM, this method is also based on the boundary integral equations(BIEs). However, in the BFM both boundary integration and variable approximation are performed on boundary faces, which are represented in parametric form exactly as the boundary representation date structure in most CAD systems. The parametric surface, which encapsulates the exact geometry of corresponding face, is discretized by surface patches in parametric space. These patches are used for the boundary integration and variable approximation. For boundary integration, the geometry data at Gaussian quadrature points, such as the coordinates, the Jacobians and the outward normals are calculated directly from the faces rather than elements, thus no geometric error will be introduced. The geometry of the computational model is exact no matter how coarse the discretization is. *Therefore, the problem of on modeling complicated thin structures faced in the BEM can be circumvented with our method.*

The BFM is implemented directly on a solid modeling data structure, namely the boundary representation (BRep). As the BRep is used in most of CAD packages, it should be possible to exploit their Open Architecture feature, and automatically obtain required coefficients (representation). Therefore, The BFM has a real potential to seamlessly interact with a CAD software, integrating easily geometric design and engineering analysis into a completely unified framework [3].

The treatment of the nearly singular integrals is a major difficulty when the commonly used BIEs are applied directly to thin-body problems(including thin voids or open cracks and shell-like structures). Efficient and accurate evaluation of the nearly singular boundary integrals may be a key factor in the overall performance of the BEM or BFM. A new technique of evaluating the nearly singular integrals is presented in this paper in detail [4]. This technique provides a new implementation of the conventional distance transformation technique to make the result stable and accurate no matter where the projection point is located. The distance functions are redefined in two local coordinate systems. A new system denoted as (α,β) is introduced here firstly. Its implementation is simpler than that of the polar system and it also performs efficiently. A new distance transformation is developed to remove or weaken the near singularities. To deal with nearly singular integrals on slender surface elements, the element subdivision scheme is employed here in combination with the new distance transformation technique. Although the element subdivision is adopted, the computational cost is reduced dramatically compared with the conventional subdivision techniques.

The proposed technique can be used to compute nearly singular integrals on both planar and curved surface elements in the same formulation. Accurate results can be obtained even when the source point is very close to the integration element, and can keep reasonable accuracy on very irregular elements. Furthermore, the accuracy of our method is much less sensitive to the position of the projection point than the conventional method.

Numerical examples have demonstrated that the BFM can simulate complicated shell-like structures easily in combination with the developed nearly singular integration technique. Higher accuracy is obtained by the BFM when compared with the BEM or EFM.

References

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