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Isogeometric Design Sensitivity Analysis of Curved Crack Problems

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An isogeometric DSA method is developed for the stress intensity factors in curved crack problems. To obtain an accurate shape sensitivity of SIFs, exact higher-order geometric information of normal vector and curvature is included in the isogeometric design sensitivity formulations. A direct differentiation method is utilized, and the size and orientation of the crack are considered as design variables for the design sensitivity analysis. In the isogeometric analysis, the NURBS basis functions in CAD system are directly used in the response analysis process, which enables an incorporation of exact geometry and higher continuity into the computational framework. The differences between the curved and the straight crack problems are (1) the accurate determination of local Cartesian coordinate system at the crack-tip, (2) the design dependence of auxiliary field and q-function in M-integral, and (3) the consideration of crack-face integral. The precise evaluation of the crack-face integral as well as the domain integral in the interaction integral formulation is necessary for the computation of the stress intensity factors for the mixed-mode curved crack problems. We demonstrate the significance of the local coordinate system when using a linear approximation of the geometry of crack in the conventional finite element approach. Also, the exact representation of geometry using the NURBS basis functions allows the precise determination of the local Cartesian coordinate system at the crack-tip, which enables the improved evaluation of the auxiliary field. The shape dependency of local coordinate system naturally leads to the variation of configuration design, and we show the importance of curvature of the crack-face curve for accurate evaluation of the design sensitivity due to the configuration design variation. Compared with the conventional finite element approach, a higher continuity of stress and strain fields are expected in the interaction integral domain. Even though having C0 continuity at the crack-tip due to the knot repetition, the higher order NURBS basis function could provide smooth stress, strain, and q-function fields. The design dependencies of auxiliary field and q-function are considered in the design sensitivity formulation for reflecting the convection effects due to the design velocity in the domain of interaction integral. Through numerical examples of the problems of the curved crack with various geometries, we demonstrate that the developed isogeometric DSA method could represent the precise geometry of crack around the crack-tip even with coarse meshes, which yields better SIF results than the conventional finite element approach.

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