Tech Science Press

ICCES, 2024, vol.30, no.3
DOI: 10.32604/icces.2024.011137

PROCEEDINGS

Improved XFEM (IXFEM): Accurate, Efficient, Robust and Reliable Analysis for Arbitrary Multiple Crack Problems

Lixiang Wang[1], Longfei Wen[2,3], Rong Tian[2,3,*] and Chun Feng[1,4,*]

[1] Key Laboratory for Mechanics in Fluid Solid Coupling Systems, Institute of Mechanics, Chinese Academy of Sciences, Beijing, 100190, China

[2] CAEP Software Center for High Performance Numerical Simulation, Beijing, 100088, China

[3] Institute of Applied Physics and Computational Mathematics, Beijing, 100088, China

[4] School of Engineering Science, University of Chinese Academy of Sciences, Beijing, 100049, China

[*] Corresponding Authors: Rong Tian; Chun Feng. Email: tian_rong@iapcm.ac.cn; fengchun@imech.ac.cn

ABSTRACT

The extended finite element method (XFEM) has been successful in crack analysis but faces challenges in modeling multiple cracks. One challenge is the linear dependence and ill-conditioning of the global stiffness matrix, while another is the geometric description for multiple cracks. To address the first challenge, the Improved XFEM (IXFEM) [1–9] is extended to handle multiple crack problems, effectively eliminating issues of linear dependence and ill-conditioning. Additionally, to overcome the second challenge, a novel level set templated cover cutting method (LSTCCM) [10] is proposed, which combines the advantages of the level set method and cover cutting technique. The present approach offers highly accurate stress intensity factor evaluation, efficient linear system solving, and robust geometric computations. Furthermore, this approach introduces novel techniques for modeling multiple evolving cracks and proposes a prediction–correction scheme for competing cracks [11]. The developed approach demonstrates accuracy, effectiveness, robustness, and reliability in analyzing arbitrary multiple crack propagation problems in 2-D elastic solids. Ongoing work aims to investigate the approach for multi-physics fracture problems (e.g., hydraulic fracturing [12–14]) by coupling the present solid solver with a fluid flow solver (e.g., [15–17]), showing promise in such scenarios.

KEYWORDS

Extra-DOF-free enrichment; level set templated cover cutting method (LSTCCM); multiple crack growth; stress intensity factor (SIF); extended finite element method (XFEM)

Acknowledgement: The authors gratefully acknowledge the financial support that they have received.

Funding Statement: L.X. Wang received the funding from the National Natural Science Foundation of China (Grant Nos. 12102059, 12472207) and the China Postdoctoral Science Foundation (Grant No. 2023M743604); L.F. Wen received the funding from the National Natural Science Foundation of China (Grant No. 12402231); R. Tian received the funding from the Science Challenge Project (Grant No. TZ2018002); and C. Feng received the funding from the National Key R&D Program of China (Grant No. 2023YFC3007203).

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. Tian, R. (2013). Extra-dof-free and linearly independent enrichments in GFEM. *Computer Methods in Applied Mechanics and Engineering, 266,* 1–22.
2. Ma, J. W., Duan, Q. L., Tian, R. (2022). A generalized finite element method without extra degrees of freedom for large deformation analysis of three-dimensional elastic and elastoplastic solids. *Computer Methods in Applied Mechanics and Engineering, 392,* 114639.
3. Tian, R., Wen, L. F. (2015). Improved XFEM—An extra-dof free, well-conditioning, and interpolating XFEM. *Computer Methods in Applied Mechanics and Engineering, 285,* 639–658.
4. Wen, L. F., Tian, R. (2016). Improved XFEM: Accurate and robust dynamic crack growth simulation. *Computer Methods in Applied Mechanics and Engineering, 308,* 256–285.
5. Wang, L. X., Wen, L. F., Wang, J. T., Tian, R. (2018). Implementations of parallel software for crack analyses based on the improved XFEM. *Scientia Sinica Technologica, 48(11),* 1241–1258.
6. Tian, R., Wen, L. F., Wang, L. X. (2019). Three-dimensional improved XFEM (IXFEM) for static crack problems. *Computer Methods in Applied Mechanics and Engineering, 343,* 339–367.
7. Xiao, G. Z., Wen, L. F., Tian, R. (2021). Arbitrary 3D crack propagation with Improved XFEM: Accurate and efficient crack geometries. *Computer Methods in Applied Mechanics and Engineering, 377,* 113659.
8. Xiao, G. Z., Wen, L. F., Tian, R., Zhang, D. G. (2023). Improved XFEM (IXFEM): 3D dynamic crack propagation under impact loading. *Computer Methods in Applied Mechanics and Engineering, 405,* 115844.
9. Wang, L. X., Wen, L. F., Xiao, G. Z., Tian, R. (2021). A templated method for partitioning of solid elements in discontinuous problems. *Chinese Journal of Rock Mechanics and Engineering, 53(3),* 823–836.
10. Wen, L. F., Tian, R., Wang, L. X., Feng, C. (2023). Improved XFEM for multiple crack analysis: Accurate and efficient implementations for stress intensity factors. *Computer Methods in Applied Mechanics and Engineering, 411,* 116045.
11. Wang, L. X., Wen, L. F., Tian, R., Feng, C. (2024). Improved XFEM (IXFEM): Arbitrary multiple crack initiation, propagation and interaction analysis. *Computer Methods in Applied Mechanics and Engineering, 421,* 116791.
12. Wang, L. X., Tang, D. H., Li, S. H., Wang, J., Feng, C. (2015). Numerical simulation of hydraulic fracturing by a mixed method in two dimensions. *Chinese Journal of Rock Mechanics and Engineering, 47(6),* 973–983.
13. Li, J., Wang, L. X., Feng, C., Zhang, R., Zhu, X. G., Zhang, Y. M. (2024). Study on the influence of perforation parameters on hydraulic fracture initiation and propagation based on CDEM. *Computers and Geotechnics, 167,* 106061.
14. Zhang, R., Wang, L. X., Li, J., Feng, C., Zhang, Y. M. (2024). Numerical analysis of perforation during hydraulic fracture initiation based on continuous–discontinuous element method. *CMES - Computer Modeling in Engineering and Sciences, 140(2),* 2103–2129.
15. Wang, L. X., Li, S. H., Ma, Z. S. (2013). A finite volume simulator for single-phase flow in fractured porous media. *Proceedings of the Sixth International Conference on Discrete Element Methods and Related Techniques*, pp. 130–135. Colorado, USA.
16. Wang, L. X., Li, S. H., Ma, Z. S., Feng, C. (2015). A cell-centered finite volume method for fluid flow in fractured porous media and its parallelization with OpenMP. *Chinese Journal of Rock Mechanics and Engineering, 34(5),* 865–875.
17. Wang, L. X., Li, S. H., Feng, C. (2023). Lagrange's equations for seepage flow in porous media with a mixed Lagrangian-Eulerian description. *Acta Mechanica Sinica, 39(11),* 323022.