Preface

'*I am always obliged to a person who has taught me a single word.*'

Progressive failure/fracture analysis of structures has been an active research topic for the past two decades. Historically, it has been addressed either within the framework of continuum computational plasticity and damage mechanics, or the discontinuous approach of fracture mechanics. The present form of linear elastic fracture mechanics (LEFM), with its roots a century old has since been successfully applied to various classical crack and defect problems. Nevertheless, it remains relatively limited to simple geometries and loading conditions, unless coupled with a powerful numerical tool such as the finite element method and meshless approaches.

The finite element method (FEM) has undoubtedly become the most popular and powerful analytical tool for studying a wide range of engineering and physical problems. Several general purpose finite element codes are now available and concepts of FEM are usually offered by all engineering departments in the form of postgraduate and even undergraduate courses. Singular elements, adaptive finite element procedures, and combined finite/discrete element methodologies have substantially contributed to the development and accuracy of fracture analysis of structures. Despite all achievements, the continuum basis of FEM remained a source of relative disadvantage for discontinuous fracture mechanics. After a few decades, a major breakthrough seems to have been made by the fundamental idea of partition of unity and in the form of the eXtended Finite Element Method (XFEM).

This book has been prepared primarily to introduce the concepts of the newly developed extended finite element method for fracture analysis of structures. An attempt has also been made to discuss the essential features of XFEM for other related engineering applications. The book can be divided into four parts. The first part is dedicated to the basic concepts and fundamental formulations of fracture mechanics. It covers discussions on classical problems of LEFM and their extension to elastoplastic fracture mechanics (EPFM). Issues related to the standard finite element modelling of fracture mechanics and the basics of popular singular finite elements are reviewed briefly.

The second part, which constitutes most of the book, is devoted to a detailed discussion on various aspects of XFEM. It begins by discussing fundamentals of partition of unity and basics of XFEM formulation in Chapter 3. Effects of various enrichment functions, such as crack tip, Heaviside and weak discontinuity enrichment functions are also investigated. Two commonly used level set and fast marching methods for tracking moving boundaries are explained before the chapter is concluded by examining a number of classical problems of fracture mechanics. The next chapter deals with the orthotropic fracture mechanics as an extension of XFEM for ever growing applications

of composite materials. A different set of enrichment functions for orthotropic media is presented, followed by a number of simulations of benchmark orthotropic problems. Chapter 5, devoted to simulation of cohesive cracks by XFEM, provides theoretical bases for cohesive crack models in fracture mechanics, classical FEM and XFEM. The snap-back response and the concept of critical crack path are studied by solving a number of classical cohesive crack problems.

The third part of the book (Chapter 6) provides basic information on new frontiers of application of XFEM. It begins with discussions on interface cracking, which include classical solutions from fracture mechanics and XFEM approximation. Application of XFEM for solving contact problems is explained and numerical issues are addressed. The important subject of dynamic fracture is then discussed by introducing classical formulations of fracture mechanics and the recently developed idea of time–space discretization by XFEM. New extensions of XFEM for very complex applications of multiscale and multiphase problems are explained briefly.

The final chapter explains a number of simple instructions, step-by-step procedures and algorithms for implementing an efficient XFEM. These simple guidelines, in combination with freely available XFEM source codes, can be used to further advance the existing XFEM capabilities.

This book is the result of an infinite number of brilliant research works in the field of computational mechanics for many years all over the world. I have tried to appropriately acknowledge the achievements of corresponding authors within the text, relevant figures, tables and formulae. I am much indebted to their outstanding research works and any unintentional shortcoming in sufficiently acknowledging them is sincerely regretted. Perhaps such a title should have become available earlier by one of the pioneers of the method, i.e. Professor T. Belytschko, a shining star in the universe of computational mechanics, Dr J. Dolbow, Dr N. Moës, Dr N. Sukumar and possibly others who introduced, contributed and developed most of the techniques.

I would like to extend my acknowledgement to Blackwell Publishing Limited, for facilitating the publication of the first book on XFEM; in particular N. Warnock-Smith, J. Burden, L. Alexander, A. Cohen and A. Hallam for helping me throughout the work. Also, I would like to express my sincere gratitude to my long-time friend, Professor A.R. Khoei, with whom I have had many discussions on various subjects of computational mechanics, including XFEM. Also my special thanks go to my students: Mr A. Asadpoure, to whom I owe most of Chapter 4, Mr S.H. Ebrahimi for solving isotropic examples in Chapter 3 and Mr A. Forghani for providing some of the results in Chapter 5.

This book has been completed on the eve of the new Persian year; a ‘temporal interface’ between winter and spring, and an indication of the beginning of a blooming season for XFEM, I hope.

Finally, I would like to express my gratitude to my family for their love, understanding and never-ending support. I have spent many hours on writing this book; hours that could have been devoted to my wife and little Sogol: the spring flowers that inspire the life.

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