

# Combined Finite-Discrete Element Method for Simulation of Hydraulic Fracturing

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**Abstract** Hydraulic fracturing is widely used in the exploitation of unconventional gas (such as shale gas). Thus, the study of hydraulic fracturing is of particular importance for petroleum industry. The combined finite-discrete element method (FDEM) proposed by Munjiza is an innovative numerical technique to capture progressive damage and failure processes in rock. However, it cannot model the fracturing process of rock driven by hydraulic pressure. In this study, we present a coupled hydro-mechanical model based on FDEM for the simulation of hydraulic fracturing in complex fracture geometries, where an algorithm for updating hydraulic fracture network is proposed. The algorithm can carry out connectivity searches for arbitrarily complex fracture networks. Then, we develop a new combined finite-discrete element method numerical code (Y-flow) for the simulation of hydraulic fracturing. Finally, several verification examples are given, and the simulation results agree well with the analytical or experimental results, indicating that the newly developed numerical code can capture hydraulic fracturing process correctly and effectively.

**Keywords** FDEM · Y-flow · Hydro-mechanical coupling · Fracture network connectivity · Seepage · Hydraulic fracturing

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## Abbreviations

|                |  |
|----------------|--|
| <b>M</b>       | Lumped mass diagonal matrices                      |
| <b>C</b>       | Damping diagonal matrices                          |
| <b>F</b>       | Nodal force vector                                 |
| <b>X</b>       | Vector of nodal coordinates                        |
| $\Delta p$     | Pressure differential between two adjacent nodes   |
| $p_1$          | Pressure of Node 1                                 |
| $p_2$          | Pressure of Node 2                                 |
| $\rho_w$       | Mass density of fluid                              |
| $g$            | Gravitational acceleration                         |
| $y_1$          | Vertical coordinate of Node 1                      |
| $y_2$          | Vertical coordinate of Node 2                      |
| $q$            | Flow rate  |
| $\mu$          | Dynamic coefficient of viscosity                   |
| $a$            | Average aperture of crack element                  |
| $\alpha_0$     | Initial value of aperture                          |
| $\alpha_{min}$ | Minimum value of aperture                          |
| $\alpha_{max}$ | Maximum value of aperture                          |
| $u_n$          | Normal displacement of crack element               |
| $L$            | Length of crack element                            |
| $f_s$          | Function of saturation                             |
| $f_n$          | Total fluid pressure on edge of triangular element |
| $s$            | Saturation of current time step                    |
| $s_0$          | Saturation of previous time step                   |
| $Q$            | Total flow rate                                    |
| $Q_{21}$       | Flow rate from Node 1 to 2                         |
| $Q_{23}$       | Flow rate from Node 3 to 2                         |
| $Q_{24}$       | Flow rate from Node 4 to 2                         |
| $p$            | Pressure of the node at the current time step      |
| $p_0$          | Pressure of the node at the previous time step     |
| $K_w$          | Bulk modulus of the fluid                          |
| $k_j$          | Permeability factor of the $j$ th crack element    |
| $\Delta t$     | Time step  |
| $\Delta t_c$   | Critical time step                                 |
| $V$            | Volume of the node at the current time step        |

# Combined Finite Discrete Element Method

**Marco Cascella**



## **Combined Finite Discrete Element Method:**

The Combined Finite-Discrete Element Method Antonio A. Munjiza,2004-04-21 The combined finite discrete element method is a relatively new computational tool aimed at problems involving static and or dynamic behaviour of systems involving a large number of solid deformable bodies Such problems include fragmentation using explosives e g rock blasting impacts demolition collapsing buildings blast loads digging and loading processes and powder technology The combined finite discrete element method a natural extension of both discrete and finite element methods allows researchers to model problems involving the deformability of either one solid body a large number of bodies or a solid body which fragments e g in rock blasting applications a more or less intact rock mass is transformed into a pile of solid rock fragments of different sizes which interact with each other The topic is gaining in importance and is at the forefront of some of the current efforts in computational modeling of the failure of solids Accompanying source codes plus input and output files available on the Internet Important applications such as mining engineering rock blasting and petroleum engineering Includes practical examples of applications areas Essential reading for postgraduates researchers and software engineers working in mechanical engineering

**The Combined Finite-Discrete Element Method** A. A. Mahmood,M. Elektorowicz,2018-04

### **The Combined Finite-Discrete Element Method Applied to the Study of Rock Fracturing Behavior in 3D.** ,2011

Since its introduction the combined finite discrete element method FEM DEM has become an excellent tool to address a wide range of problems involving fracturing and fragmentation of solids Within the context of rock mechanics the FEM DEM method has been applied to many complex industrial problems such as block caving deep mining techniques rock blasting seismic waves packing problems rock crushing problems etc In the real world most of the problems involving fracture and fragmentation of solids are three dimensional problems With the aim of addressing these problems an improved 2D 3D FEM DEM capability has been developed at Los Alamos National Laboratory LANL These capabilities include state of the art 3D contact detection contact interaction constitutive material models and fracture models In this paper Split Hopkinson Pressure Bar SHPB Brazilian experiments are simulated using this improved 2D 3D FEM DEM approach which is implemented in LANL s MUNROU Munjiza Rougier code The results presented in this work show excellent agreement with both the SHPB experiments and previous 2D numerical simulations performed by other FEM DEM research groups

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rock blasting applications a more or less intact rock mass is transformed into a pile of solid rock fragments of different sizes which interact with each other The topic is gaining in importance and is at the forefront of some of the current efforts in computational modeling of the failure of solids Accompanying source codes plus input and output files available on the Internet Important applications such as mining engineering rock blasting and petroleum engineering Includes practical examples of applications areas Essential reading for postgraduates researchers and software engineers working in mechanical engineering

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Sarhosis, Vasilis, Bagi, Katalin, Lemos, José V., Milani, Gabriele, 2016-06-09 The Discrete Element Method DEM has emerged as a solution to predicting load capacities of masonry structures As one of many numerical methods and computational solutions being applied to evaluate masonry structures further research on DEM tools and methodologies is essential for further advancement Computational Modeling of Masonry Structures Using the Discrete Element Method explores the latest digital solutions for the analysis and modeling of brick stone concrete granite limestone and glass block structures Focusing on critical research on mathematical and computational methods for masonry analysis this publication is a pivotal reference source for scholars engineers consultants and graduate level engineering students

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Pradeep K. Singh, Amalendu Sinha, 2012-11-05 Rock Fragmentation by Blasting contains the papers presented at the 10th International Symposium on Rock Fragmentation by Blasting New Delhi India 26 29 November 2012 and represents the most advanced forum on blasting science and technology The contributions cover all major recent advancements in blasting and fragmentation from realistic tre

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Discrete Element Methods Benjamin K. Cook,Richard P. Jensen,2002 Proceedings of the Third International Conference on Discrete Element Methods held in Santa Fe New Mexico on September 23 25 2002 This Geotechnical Special Publication contains 72 technical papers on discrete element methods DEM a suite of numerical techniques developed to model granular materials rock and other discontinua at the grain scale Topics include DEM formulation and implementation approaches coupled methods experimental validation and techniques including three dimensional particle representations efficient contact detection algorithms particle packing schemes and code design Coupled methods include approaches to linking solid continuum and fluid models with DEM to simulate multiscale and multiphase phenomena Applications include fundamental investigations of granular mechanics micromechanical studies of powder soil and rock behavior and large scale modeling of geotechnical material processing mining and petroleum engineering problems

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