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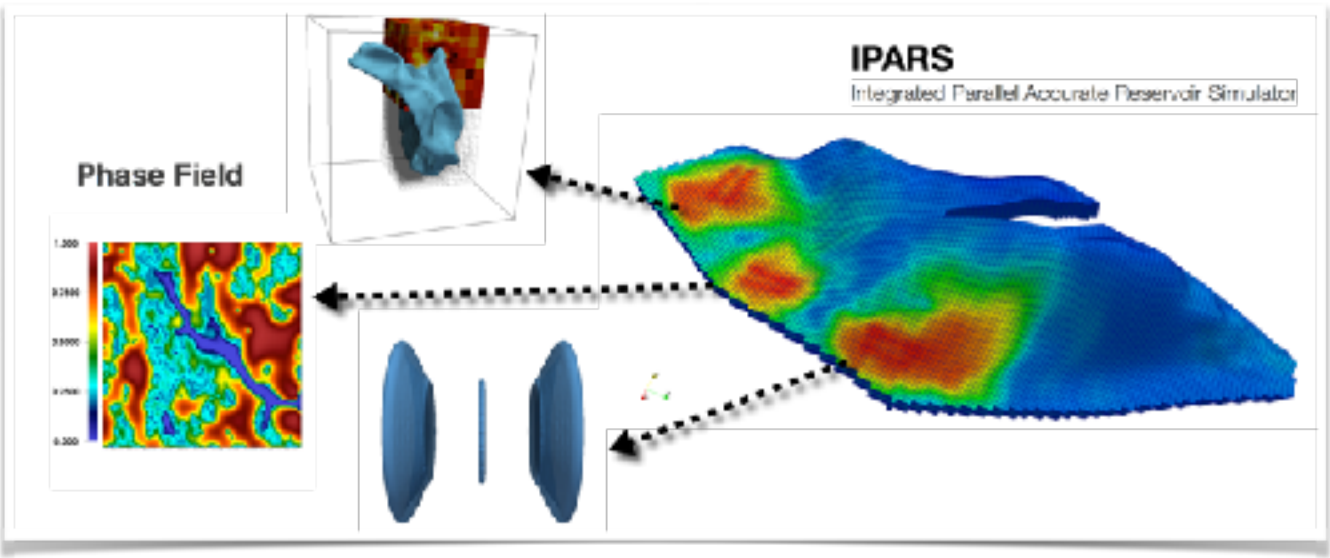

IPACS **I**ntegrated **P**hase field **A**dvanced **C**rack **S**imulator.

User Manual

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July 5, 2017

Manual Version: 2016-V1.2

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IPACS INTEGRATED PHASE FIELD ADVANCED CRACK SIMULATOR

Objective

Fracture propagation in heterogeneous porous media using dynamic adaptive finite element phase field approach.

1. Software Requirement

- CMake version 2.8.8 or later
- deal.II-8.0 or higher
- Trilinos 11.4.1 or higher which is compatible with deal.II
- p4est 0.3.4.2
- open mpi

2. Basic Setup

i) Setup 'CMakeLists.txt' file. (enables to switch dim=2/dim=3)

ii) Need a parameter file to define the problem.

iii) Need directories to save the output files : output/

iv) Need an appropriate mesh file in the directory: input_msh/

3. How to run

i) ./clean : Cleans up all the output files.

ii) ./Set_Cmake : Initialize/make the program : need to give the right path for deal.II

iii) Command to run : ./IPACS-V*.* parameter_file

iv) Run it parallel : mpirun -np "# of cores" ./IPACS-V*.* parameter_file

4. Note

IPACS is a research code and general parameter specifications have not been included and require code modifications.
If you have any technical questions please email to shlee@ices.utexas.edu / thomas.wick@polytechnique.edu.

FEATURES

1. Background

- Quasi-monolithic formulation for the displacement-phase-field system.
- Biot coefficient (alpha) = 0 or 1 .
- Constant pressure is applied for pressurized fracture propagation.
- Primal dual active set algorithm for multiple interactions.
- Predictor corrector dynamic mesh adaptivity.
- Fixed stress splitting for coupling flow and geomechanics.
- Fracture initialization with realistic field data.

2. Selected Publications for Reference.

- [1] M. Mikelic, M. F. Wheeler, T. Wick; A phase-field method for propagating fluid-filled fractures coupled to a surrounding porous medium, SIAM Multiscale Modeling and Simulation, Vol. 13(1), 2015, pp. 367-398
- [2] T.Heister, M.Wheeler, T.Wick; A primal-dual active set method and predictor-corrector mesh adaptivity for computing fracture propagation using a phase field approach.
- [3] T. Wick, S. Lee, M. F. Wheeler; 3D Phase-Field for Pressurized Fracture Propagation in Heterogeneous Media ECCOMAS and IACM Coupled Problems, May 2015 at San Servolo, Venice/Italy
- [4] S. Lee, M.F. Wheeler, T. Wick; Pressure and fluid-driven fracture propagation in porous media using an adaptive finite element phase field model Comp. Meth. Appl. Mech. Engrg., Volume 305, 15 June 2016, Pages 111–132, DOI: 10.1016/j.cma.2016.02.037, 2016
- [5] S. Lee, M. F. Wheeler, T. Wick, S. Srinivasan; Initialization of phase-field fracture propagation in porous media using probability maps of fracture networks, Mechanics Research Communications, accepted in April 2016, doi: 10.1016/j.mechrescom.2016.04.002
- [6] S. Lee, A. Mikelic, M. F. Wheeler*, T. Wick; Phase-field modeling of proppant-filled fractures in a poroelastic medium, Comp. Meth. Appl. Mech. Engrg. DOI: 10.1016/j.cma.2016.02.008, 2016
- [7] S. Lee*, M.F. Wheeler, T. Wick, Iterative coupling of flow, geomechanics and adaptive phase-field fracture including a level-set crack width approach, in revision for publication to Journal of Computational and Applied Mathematics, ICES Report 16-23

3. Examples of pressurized fracture propagations

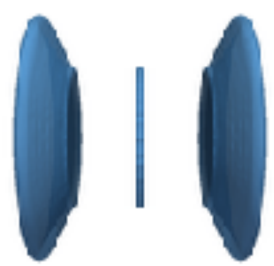


Figure 1. Stress shadowed effect

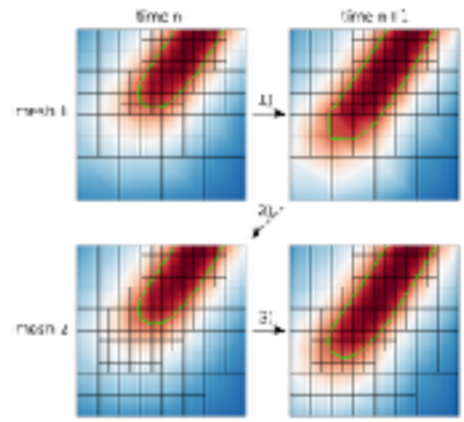


Figure 2. Predictor-corrector mesh refinement steps

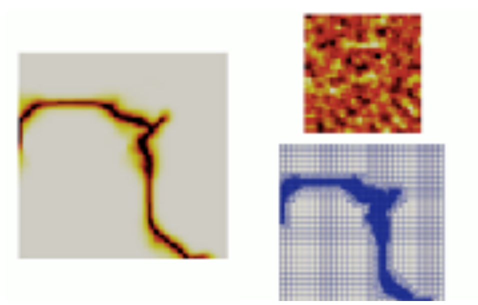


Figure 3. Multiple fracture joining and branching in three dimensional heterogeneous media.

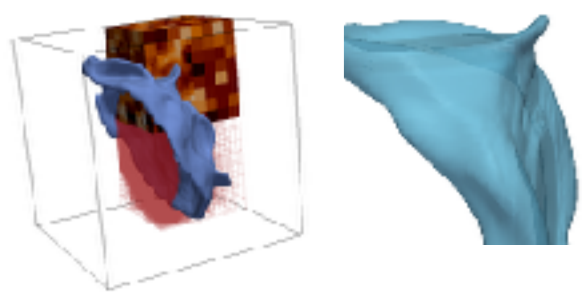


Figure 4. Multiple fracture joining and branching in heterogeneous media.

4. Examples of fluid filled fracture propagations

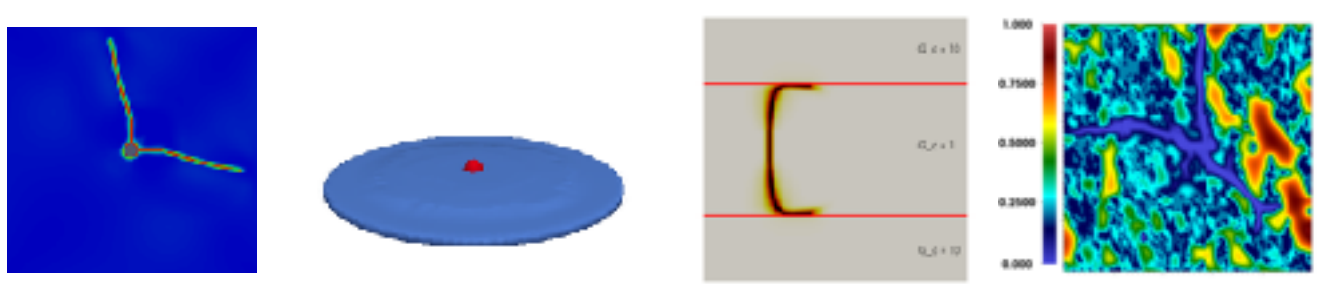


Fig 6. Two and Three dimensional fluid filled fracture propagating in homogeneous and heterogeneous porous medium.

THE PARAMETER FILE

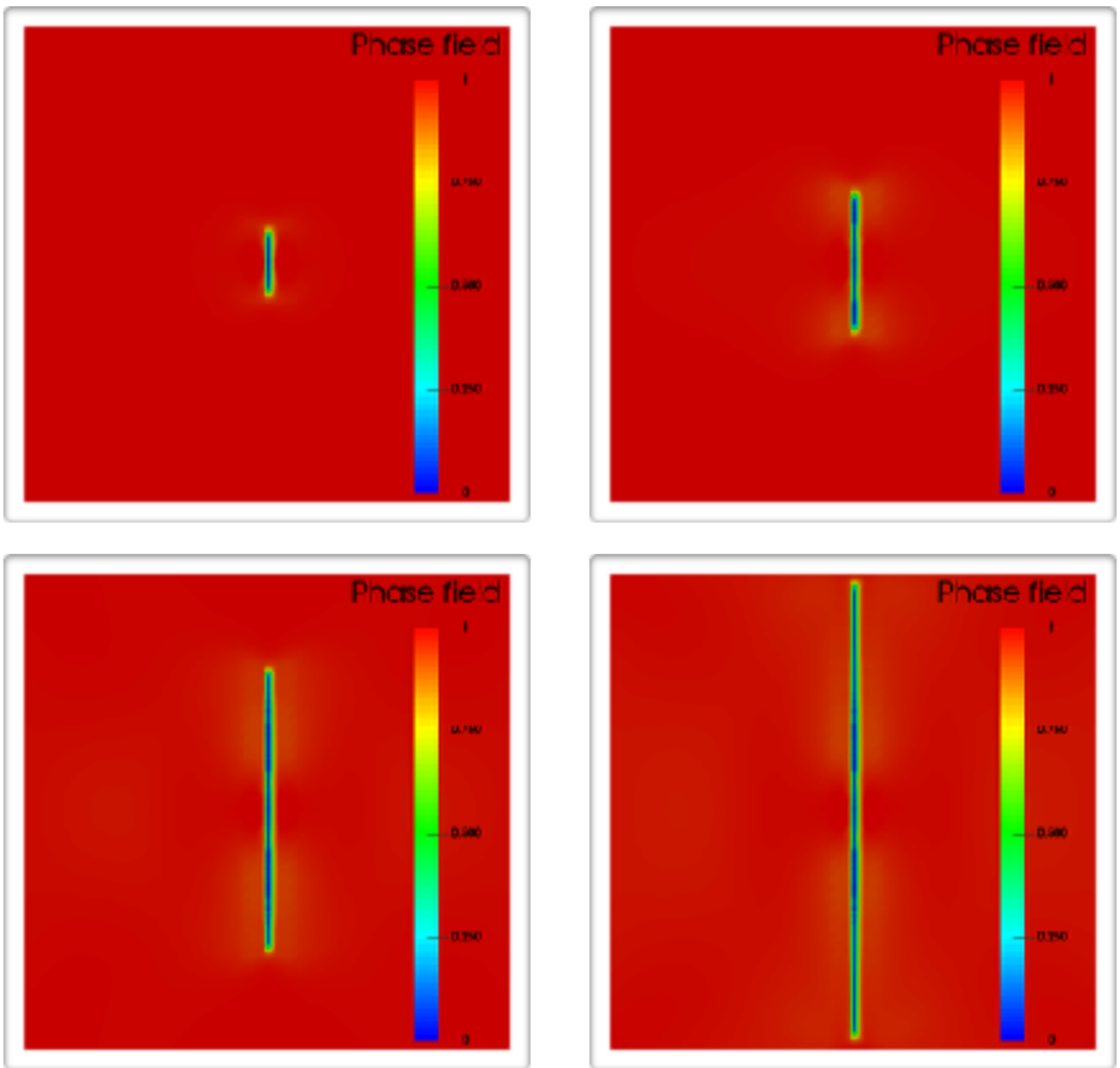
Variable names	Format (default values)	Definition and Description
length 1	double (0.0)	Defines the distance between the parallel fractures. See example 4.
length 2	double (0.0)	
darcy switch	bool (true)	False : pressurized fracture propagation. True : Fluid filled fracture propagation.
Global pre-refinement steps	int (5)	Number of levels for pre-refined global mesh refinement. Default 5 levels.
Local pre-refinement steps	int (4)	Number of levels for pre-refined local mesh refinement.
Adaptive refinement cycles	int (0)	Used for debugging.
Max No of timesteps	int	Maximum number of time steps.
Timestep size	double	Time step size
Timestep size to switch to	double	Used for debugging.
Switch timestep after steps	int	Used for debugging.
outer solver	active set	Solver for energy minimization. (Options available to use Simple penalization method or Augmented Lagrangian)
test case		Name of examples.
ref strategy	phase field	Dynamic refinement for phase field; predictor-corrector method.
value phase field for refinement	double (0.8)	Criteria for mesh refinement. Mesh is refined if the phase field value is less than 0.8 (default).
Output filename	char	Name for your output file.
K reg	double (1e-10*h)	Regularization kappa for the phase field. See references.
Eps reg	double (2*h)	Length of the diffusive zone, epsilon.
Gamma penalization	double (0.0)	Simple penalization method.
use peaceman well model	bool	Option for Peaceman well model

Variable names	Format (default values)	Definition and Description
Pressure	double	Required for pressurized fracture case. Pressure assume to increase in time.
Fracture toughness G_c	double	Fracture toughness values
Fracture toughness G_c_2	double	
Density solid	double	Density of the solid.
Poisson ratio nu	double	Poisson ratio
E modulus	double	Young's modulus
alpha time		Used for debugging.
pressure diff x1	double	Interpolation values for the pressure diffraction system. See references.
pressure diff x2	double	
pressure wellbore	double	Injection rate or specified pressure at well bore for fluid filled fractures
alpha Biot coefficient	double	alpha = 0 : pressurized fracture propagation alpha != 0 : fluid filled fracture propagation
M Biot	double	Biot modulus value
Compressibility Fracture	double	Compressibility coefficient for the fluid in the fracture(s).
Viscosity Reservoir	double	Viscosity for the fluid in the reservoir
Viscosity Fracture	double	Viscosity for the fluid in the fracture(s).
Permeability Reservoir	double	Permeability of the reservoir, if it is constant. Heterogeneities need to specified for general case.
Density Reservoir	double	Density of the fluid.
tol fixed stress	double	Stopping criteria of phase field for fixed stress iterations
tol fixed stress two	double	Stopping criteria of pressure for fixed stress iterations
Use Direct Inner Solver	type	Options for the solver. (Direct, GMRES)
Newton lower bound	double (1.0e-8)	Stopping criteria for Newton solver of the displacement-phase field system

Variable names	Format (default values)	Definition and Description
Newton lower bound pressure	double	Stopping criteria for Newton solver of the linearized pressure system
Newton maximum steps	int	Maximum number of Newton steps allowed
Upper Newton rho	double	Used for debugging.
Line search maximum steps	inte	Line search for Newton method
Line search damping	double	Line search for Newton method
Decompose stress in rhs	double	Debugging parameter
Decompose stress in matrix	double	Debugging parameter

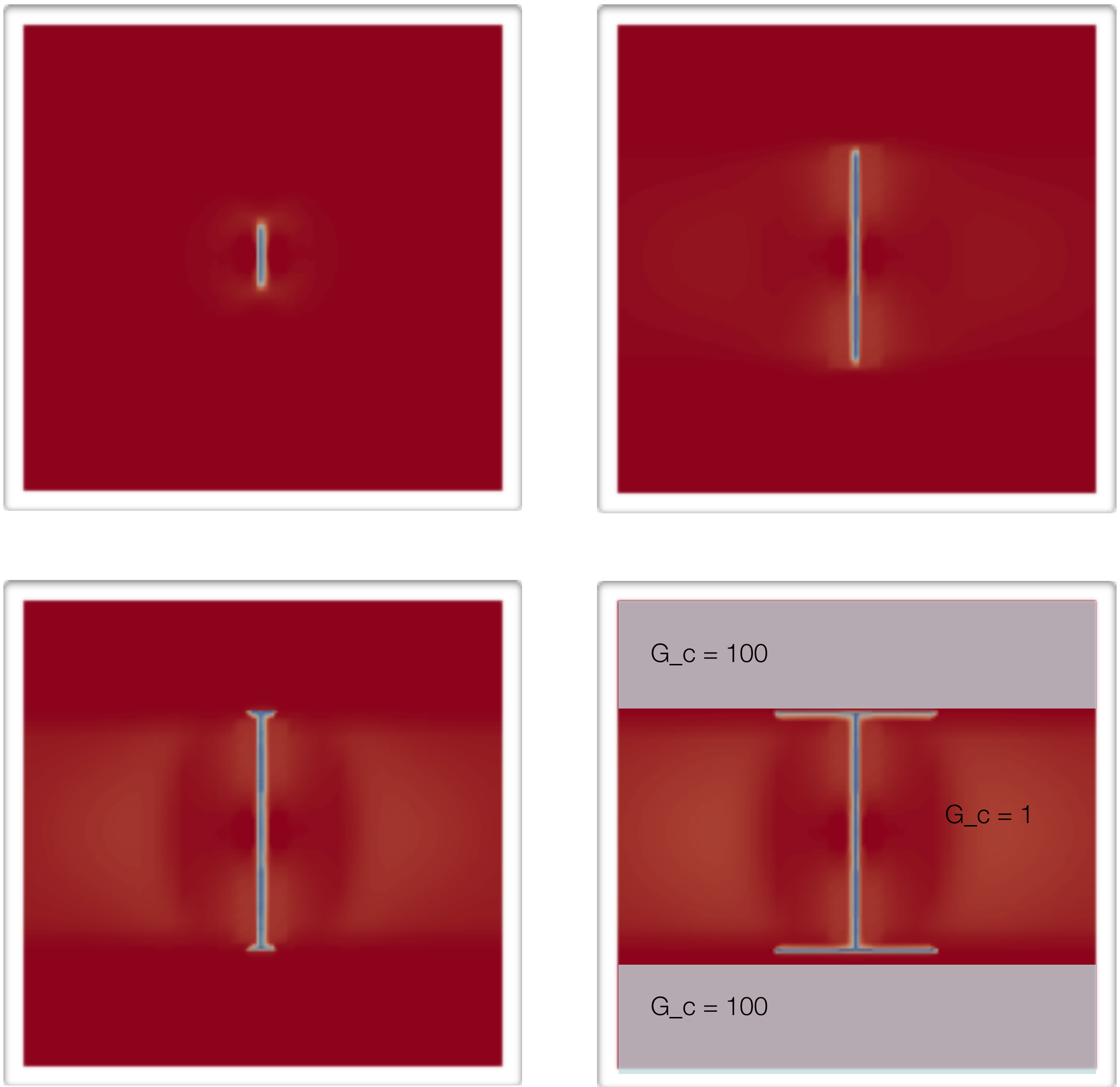
Example 1. A singe fracture

- Parameter file : 2D_Single.prm provided
- (0m,0m) x (4m,4m)



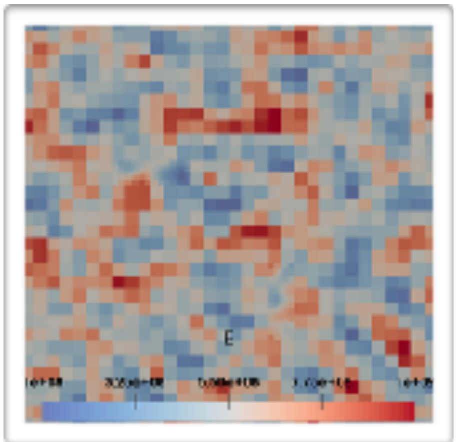
Example 2. A single fracture in a layered medium.

- Parameter file : 2D_Single_Gc.prm provided

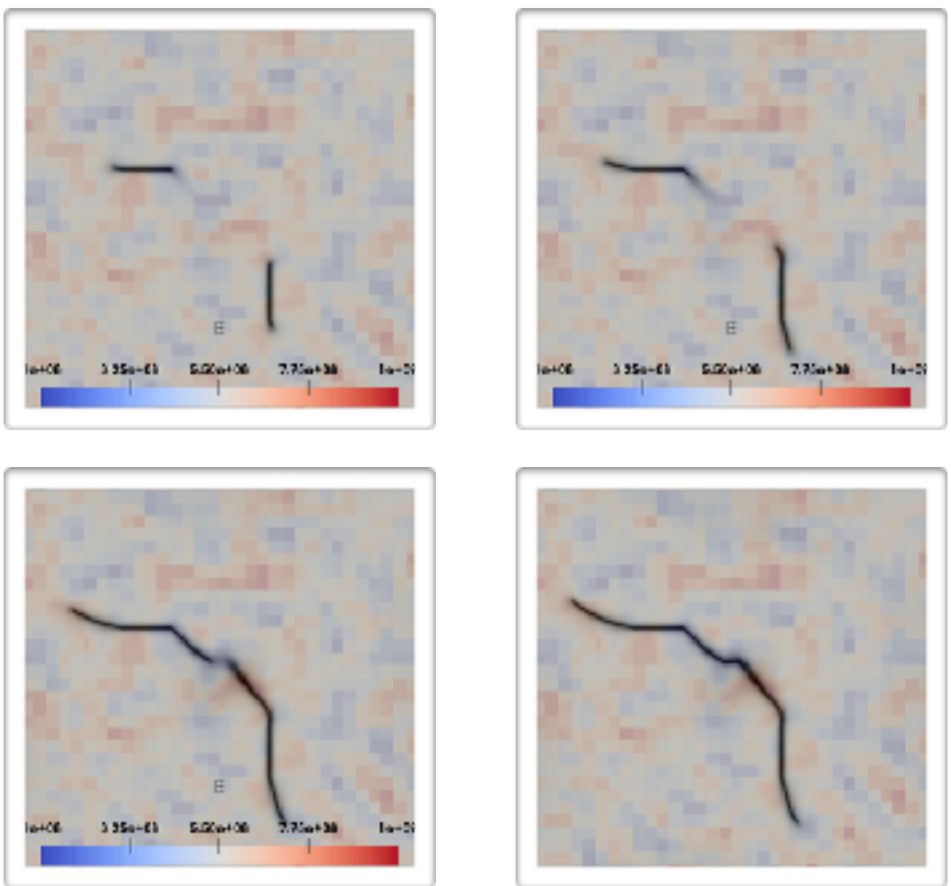


Example 3. Multiple fractures in a heterogeneous medium.

- Parameter file : 2D_Mul_Het.prm provided



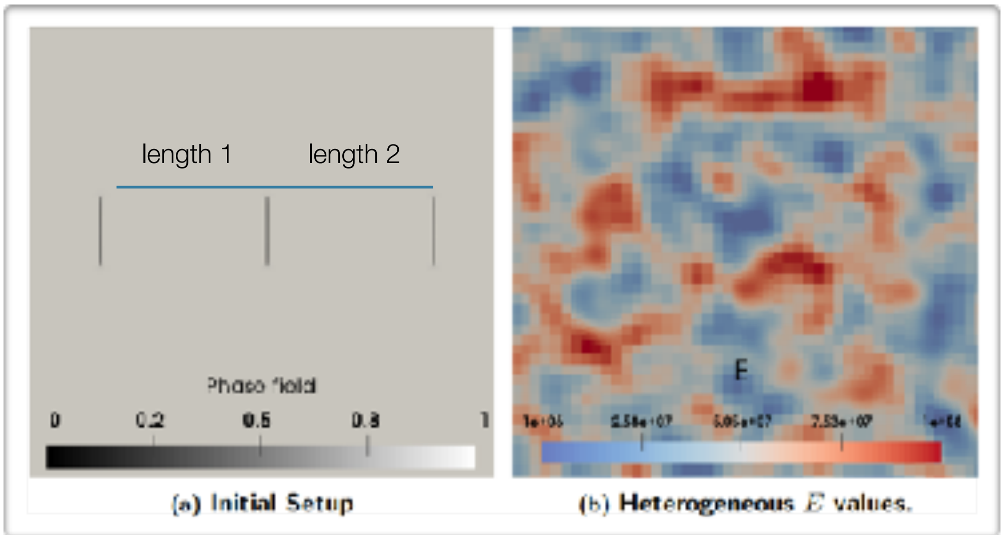
(0,0) X (4,4) Heterogeneous medium with randomly distributed Young's modulus (E) values.



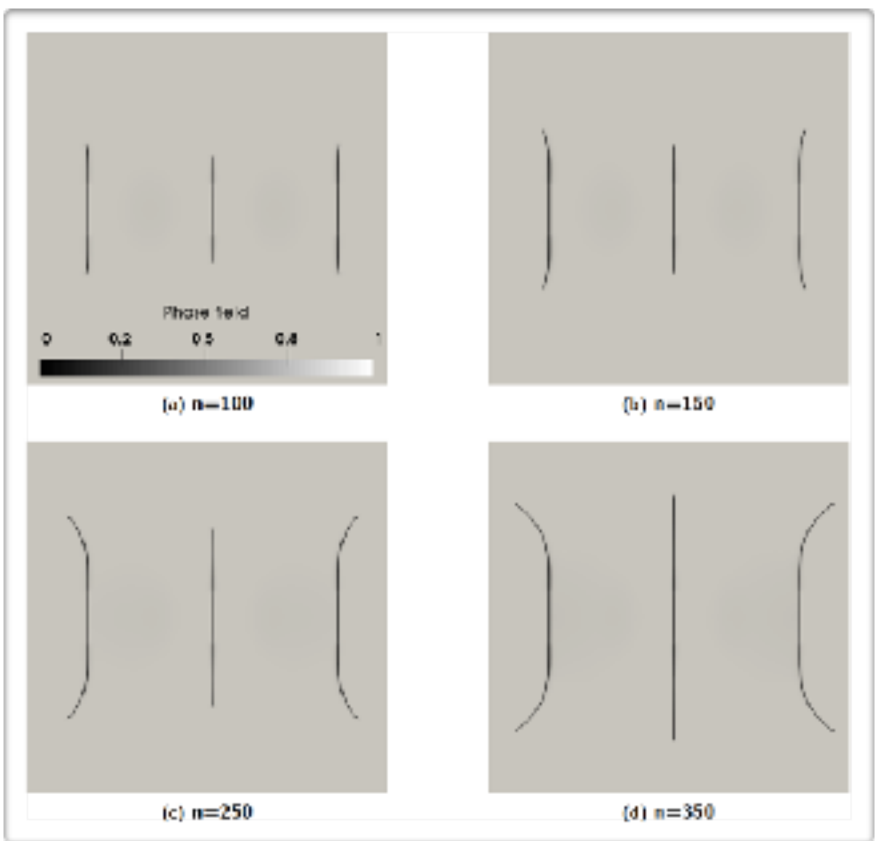
Multiple fractures join and branch.

Example 4. Multiple parallel fractures in a homogeneous/heterogeneous medium.

- Parameter files provided

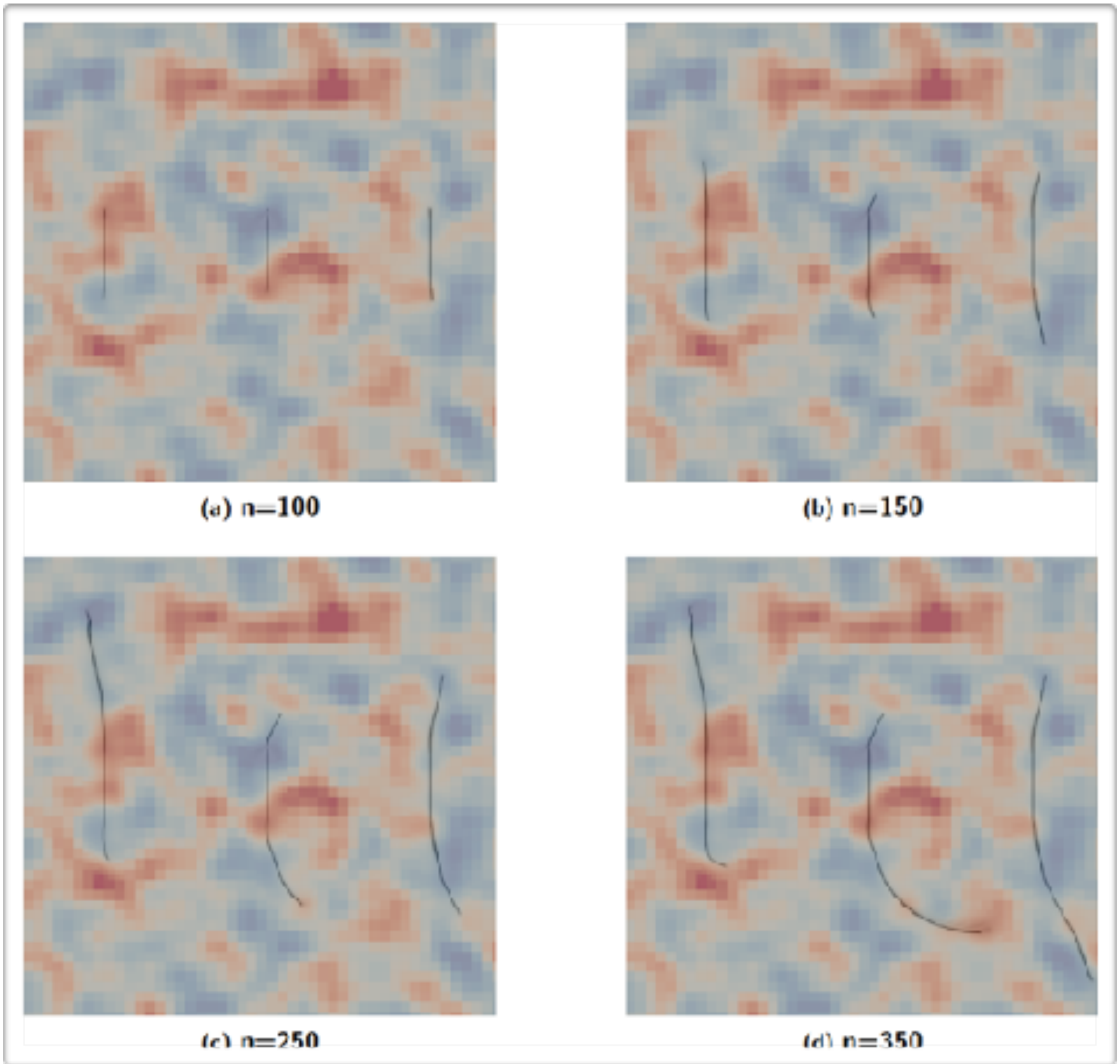


(a) Initial Setup (b) Heterogeneous E values.



(a) n=100 (b) n=150 (c) n=250 (d) n=350

A two dimensional homogeneous medium



A two dimensional heterogeneous medium

Example 5. A fracture in a 3D homogeneous medium.

- Parameter file : 3D_Single.prm provided