Monte-Carlo Simulation of Failure Phenomena using Particle Discretization

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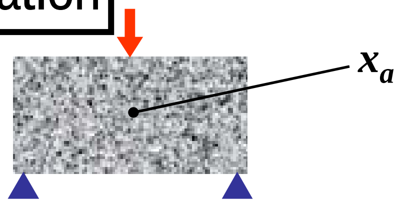
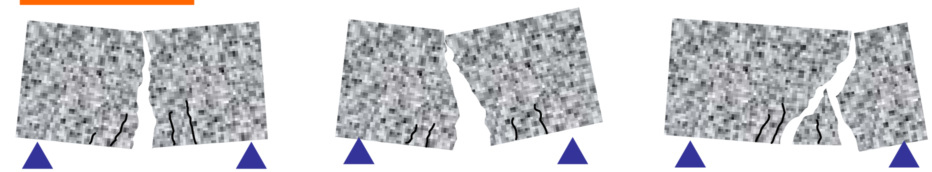
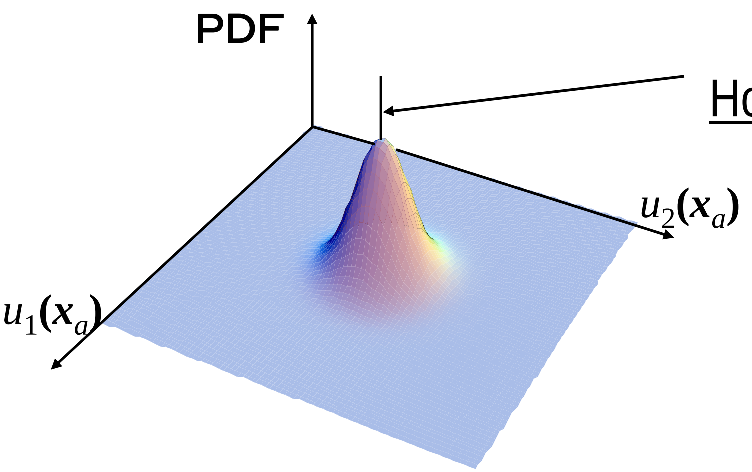
Motivation

Deformation

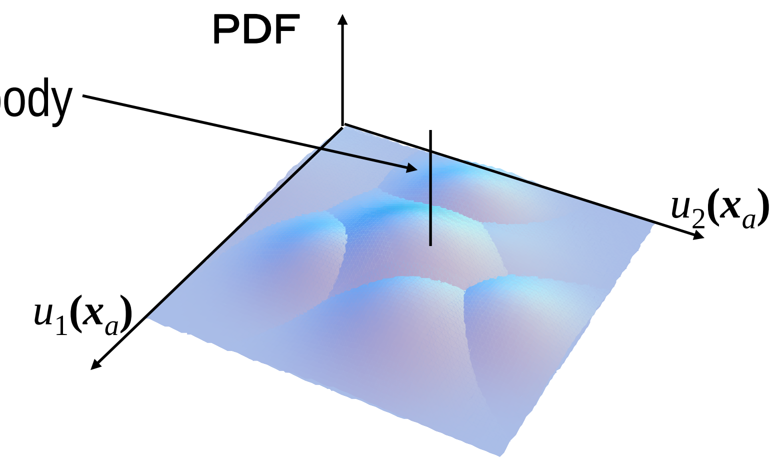


Failure





Solution for
Homogeneous body



Phenomenon ≒ Behavior of Homogeneous body

Phenomenon ≠ Behavior of Homogeneous body

Accurate solution for homogeneous body with expensive discretization

Utter Significance

Almost Meaningless

Things to Discuss on Analysis of Failure Behavior

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◆Effect of local heterogeneity

- Behavior of ideally homogeneous body ≠ What really happens

  （extensive, expensive analysis on ideally homogeneous body ・・・？）
- Convergence in local sense needed?

  （Failure phenomena do not converge in local sense）
- Methods with wide variety of failure patterns depending on local heterogeneity

  （Which could be called mesh dependence ）

◆Number of DOF

- “ Fine Mesh ⇒ High Accuracy “ does not always hold
- Proper order of discretization depending on the scale of local heterogeneity

Objectives

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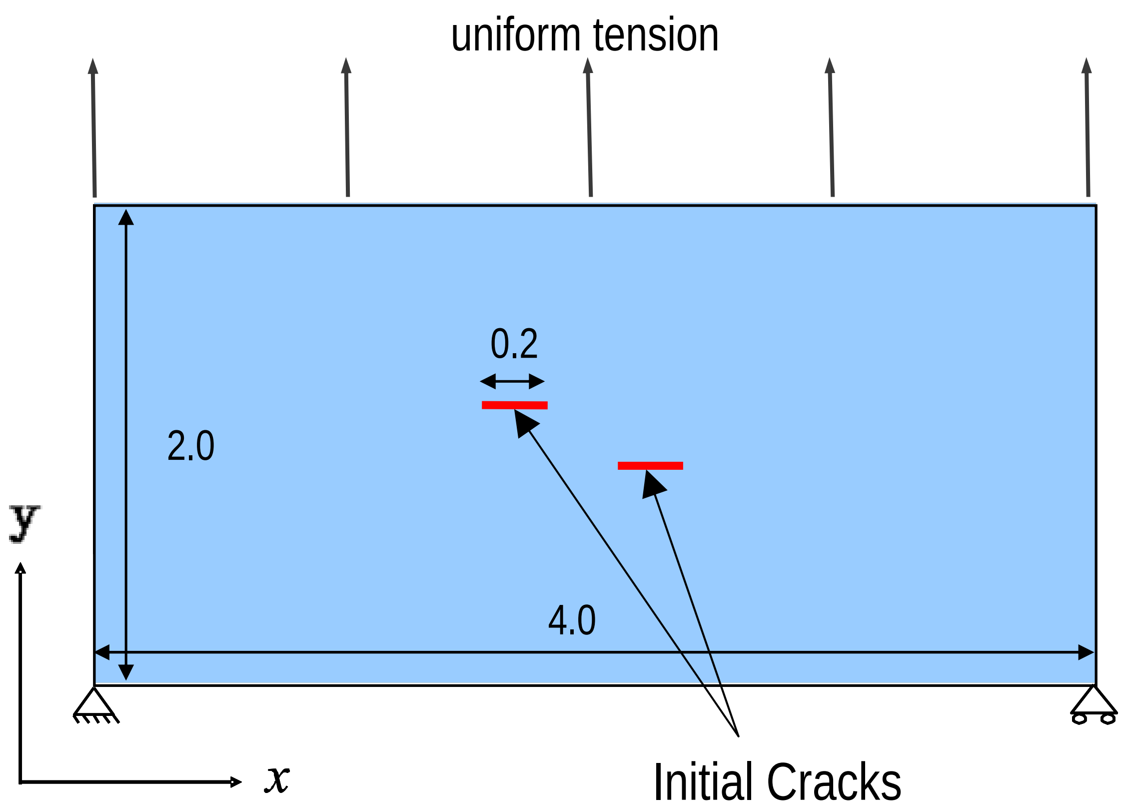
- Numerical analysis on failure behavior of bodies with local heterogeneity
- See the difference between the failure behavior of ideally homogeneous body and that of locally heterogeneous bodies
- Examine the applicability of Particle Discretization Scheme (FEM-β) to analysis of failure behavior of bodies with local heterogeneity

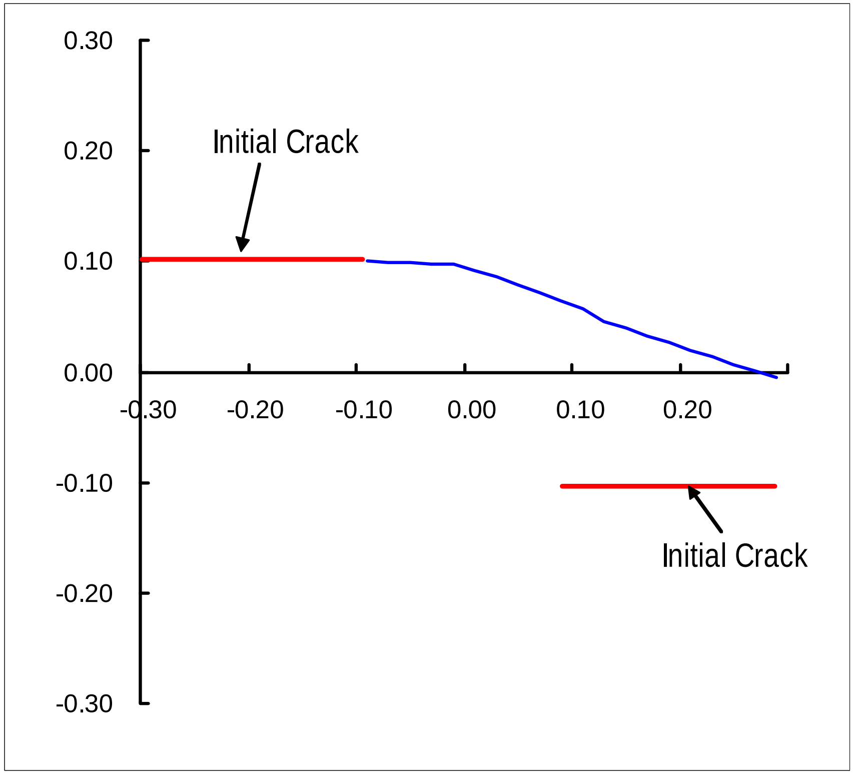
Example Problem



Young's modulus	1.0
Poisson's ratio	0.25
Disp. B.C.	0.1 (vertical)

Ideally Homogeneous Body

Ideally Homogeneous Body

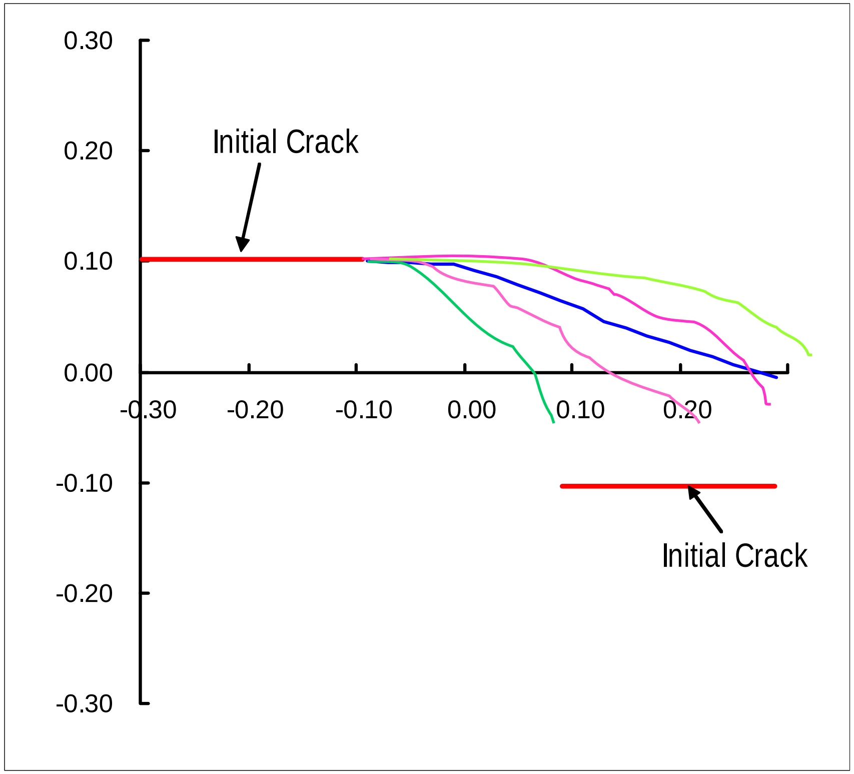


Kamaya and Totsuka, Corrosion Science, 2002

Mesh: very fine, incremental crack growth
Direction: based on the energy release rate for virtual extension of the crack

The only one pair of crack path is obtained

Body with Local Heterogeneity --- What we expect



Different crack paths depending on local heterogeneity?

Do they converge to homogeneous solution?

Stochastic Treatment

Stochastic Treatment

Brute force:
Monte-Carlo simulation using models with
different distribution of material properties (stiffness, strength etc.)

but…

Meshless related methods: sophisticated discretization requires
relatively high computational cost
Adaptive mesh: re-mesh at each step costs a lot

We need

a method with i) less computational cost
ii) simple treatment of failure
iii) no change in configuration

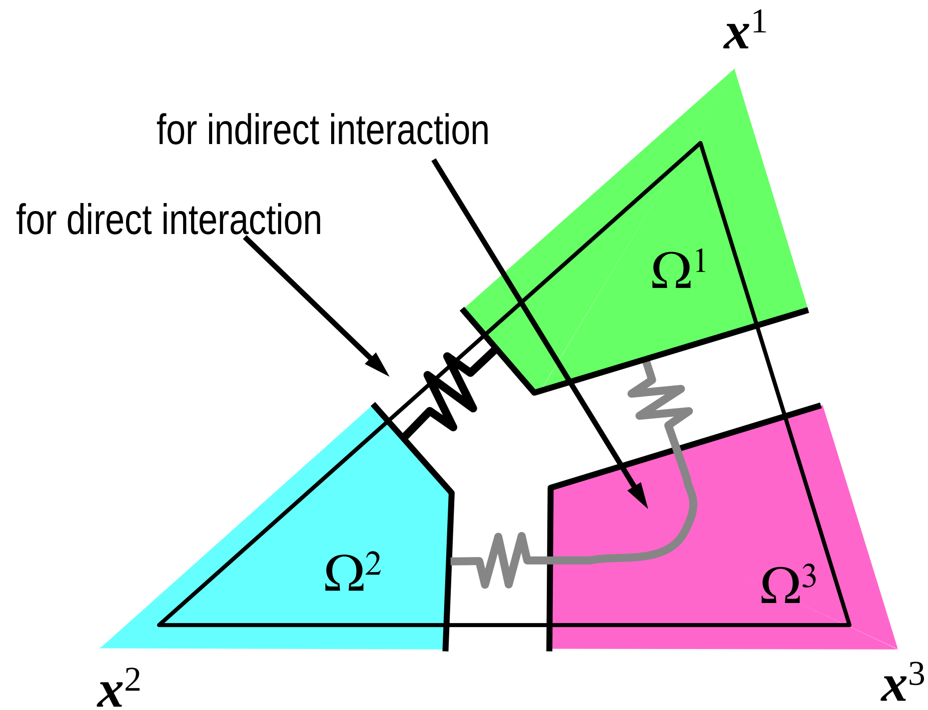
Easy Treatment of Failure in FEM-b

stiffness matrix of FEM-β

$$\begin{bmatrix} [k_{11}] & [k_{12}] & [k_{13}] \\ [k_{21}] & [k_{22}] & [k_{23}] \\ [k_{31}] & [k_{32}] & [k_{33}] \end{bmatrix}$$

$$[k_{12}] = [k_{12}^{\text{direct}}] + [k_{12}^{\text{indirect}}]$$

Spring properties are rigorously determined with material properties; E and ν



Appropriately change the components of stiffness matrix/spring constants, according to a suitable failure criterion

Monte-Carlo Simulation of Crack Propagation in Locally Heterogeneous Body

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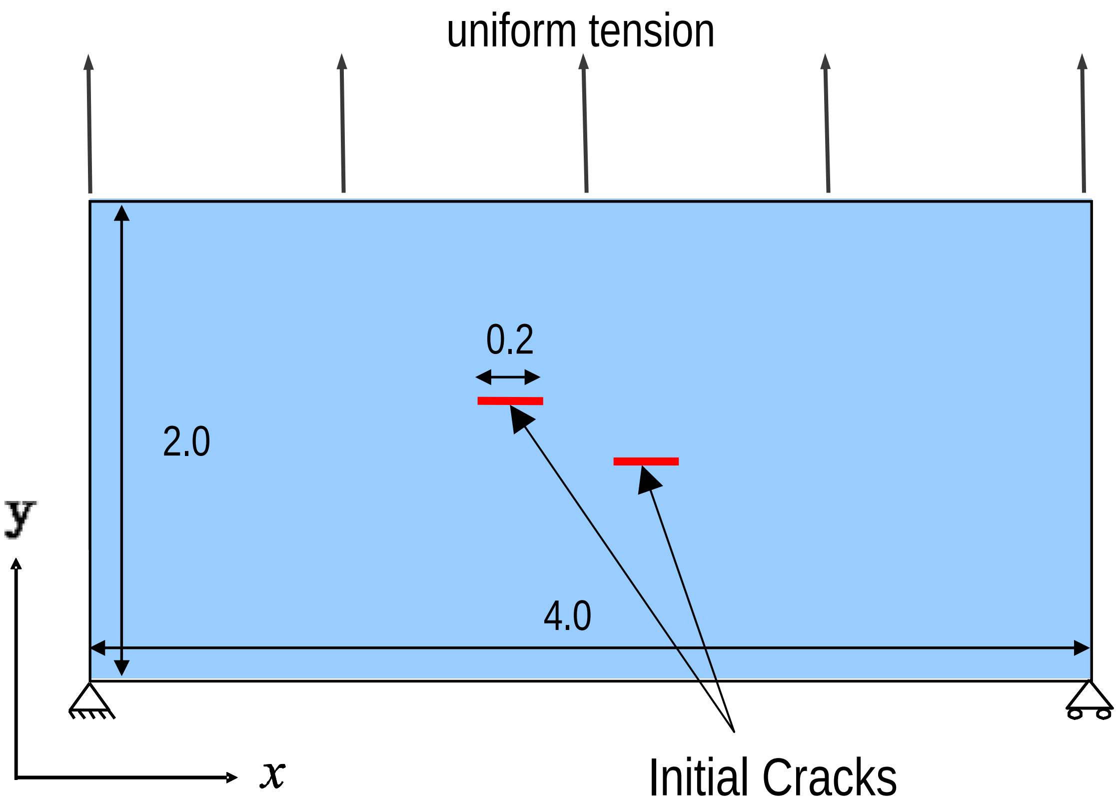

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1000 models with different mesh **geometry**

↓

1000 models with different distribution of **material strength**

Example of Crack Path

Let’s have a look at animations

Example of Crack Path

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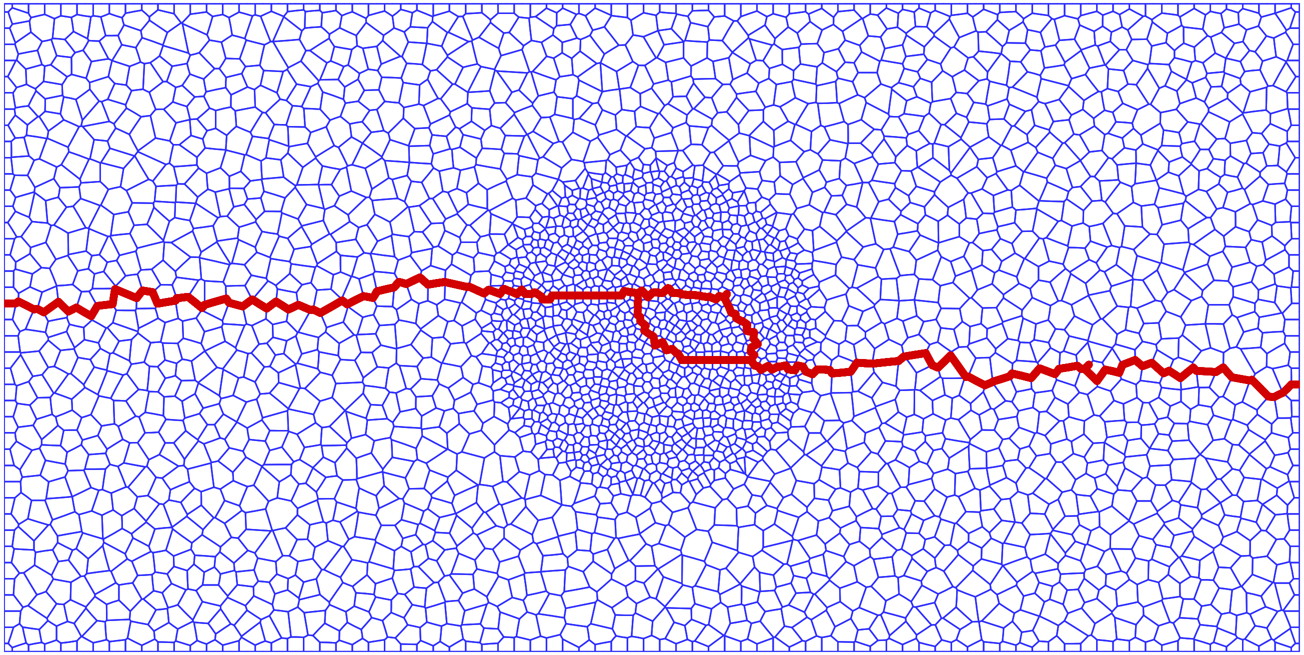
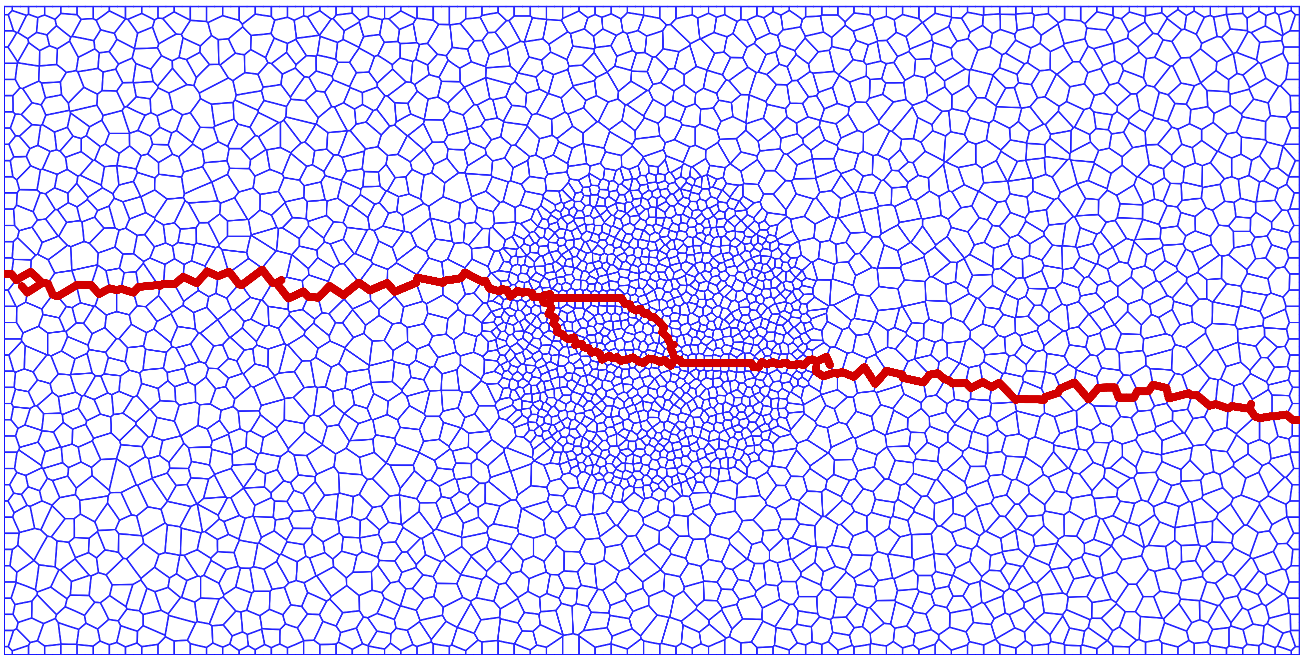
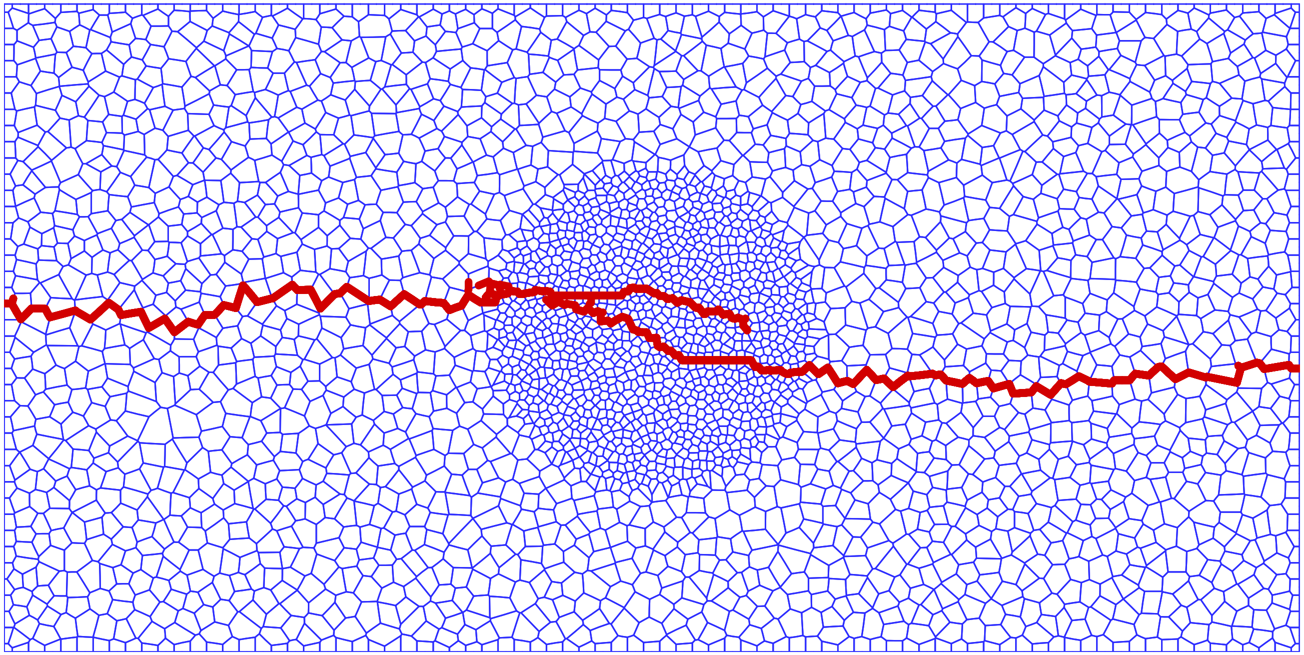


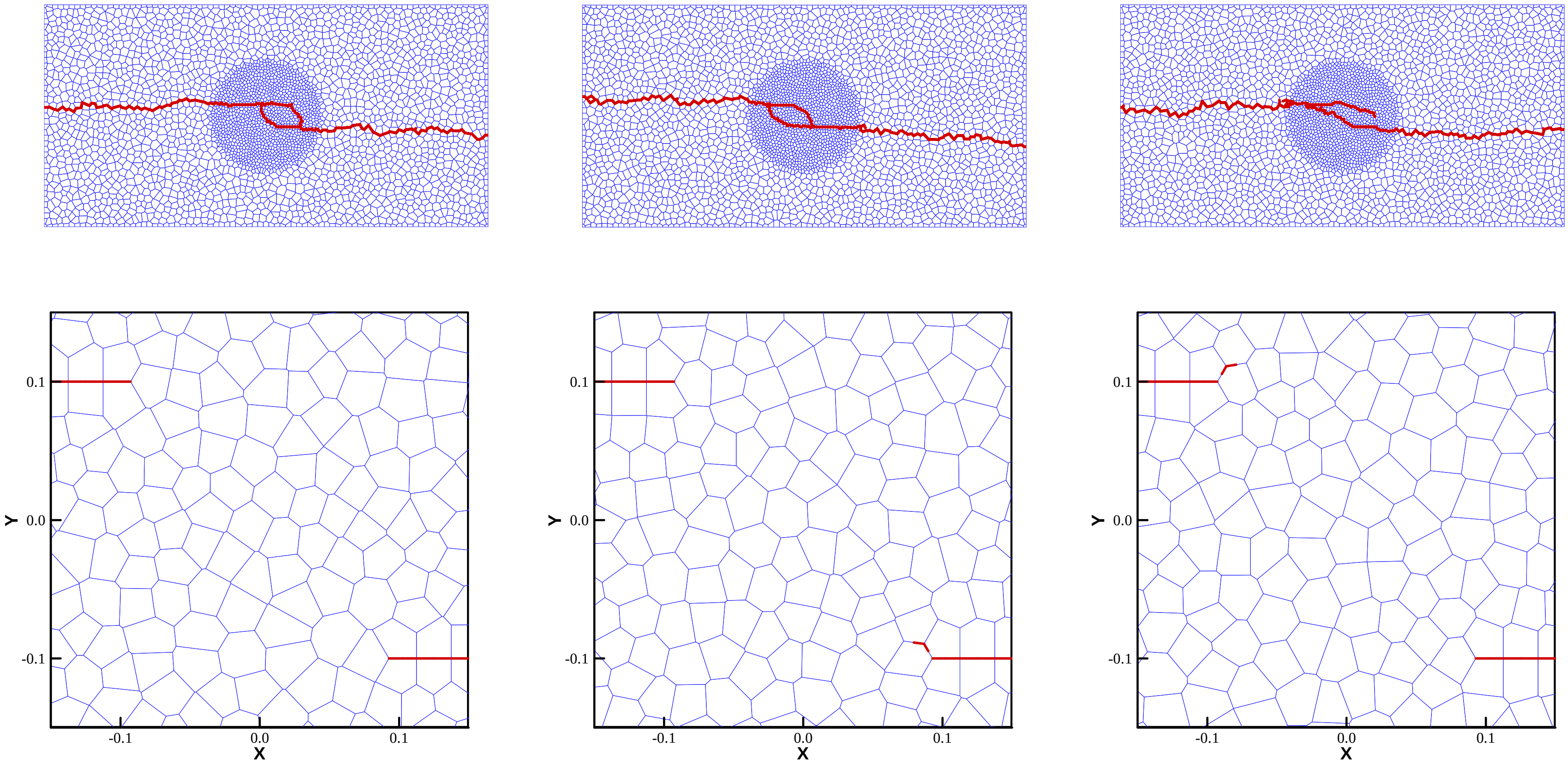
Example of Crack Path



Example of Crack Path

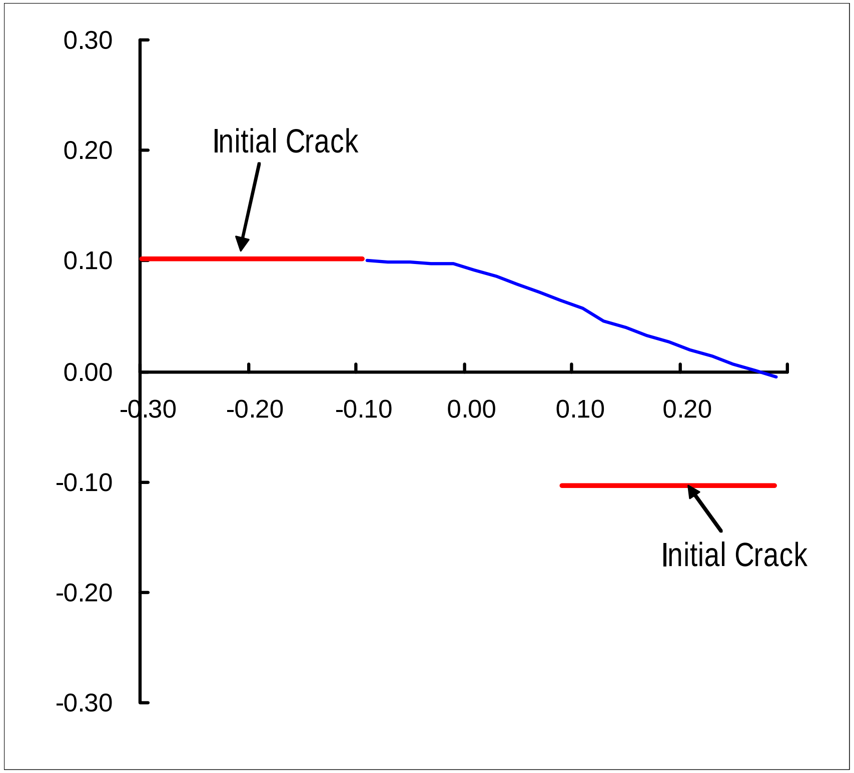


Source of the Difference

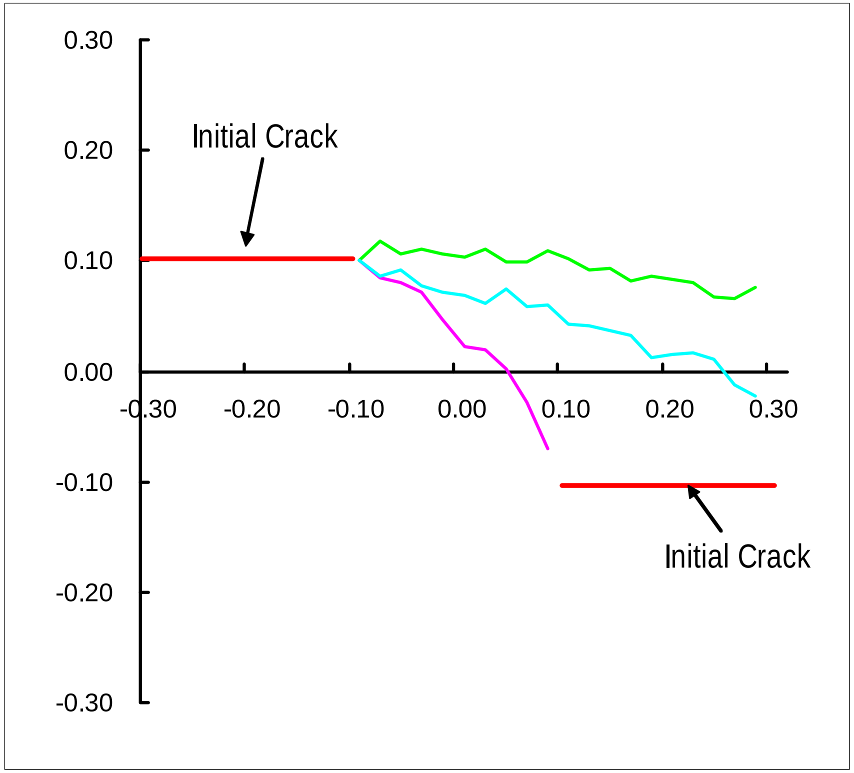


Qualitative Comparison between Ideally Homogeneous and Locally Heterogeneous bodies

Ideally Homogeneous Body

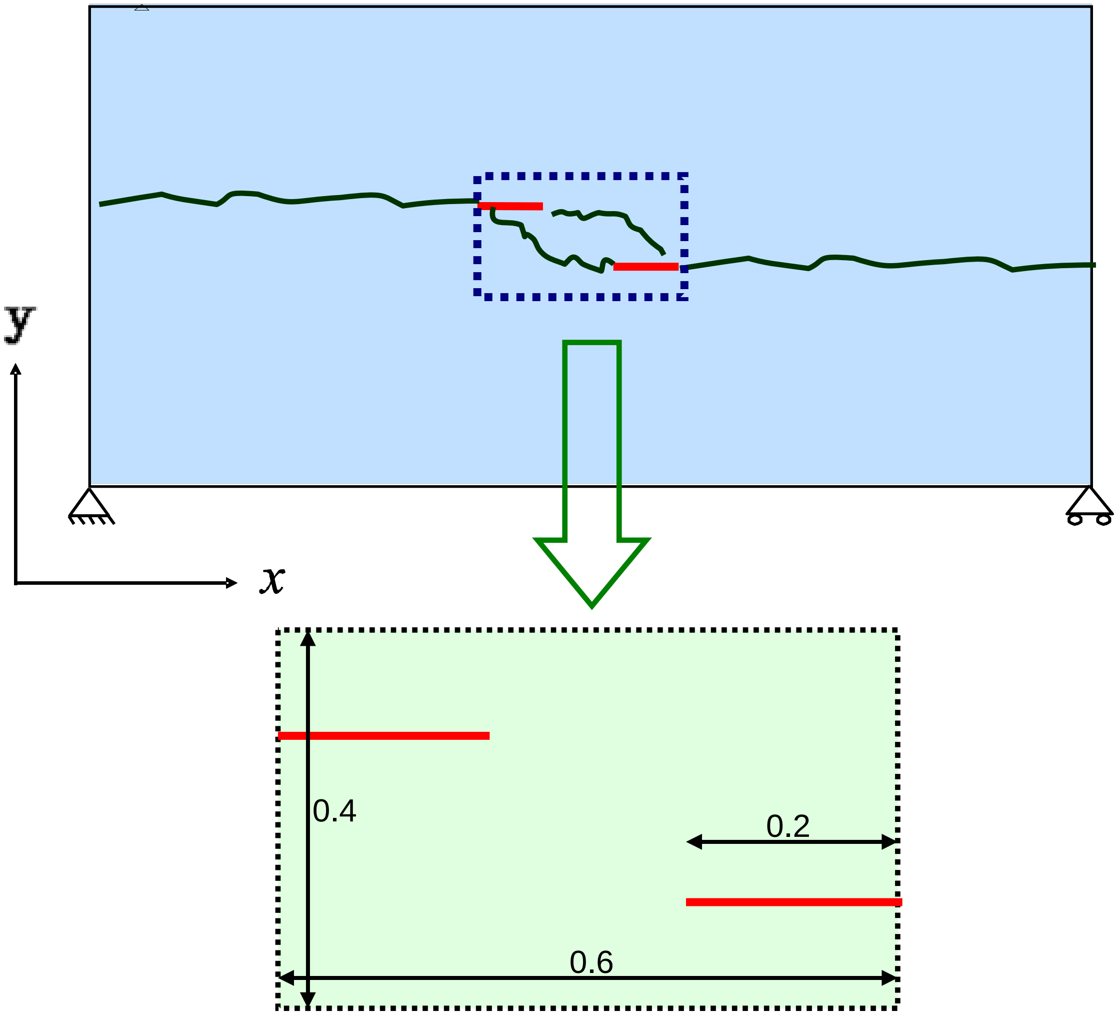


Locally Heterogeneous Bodies



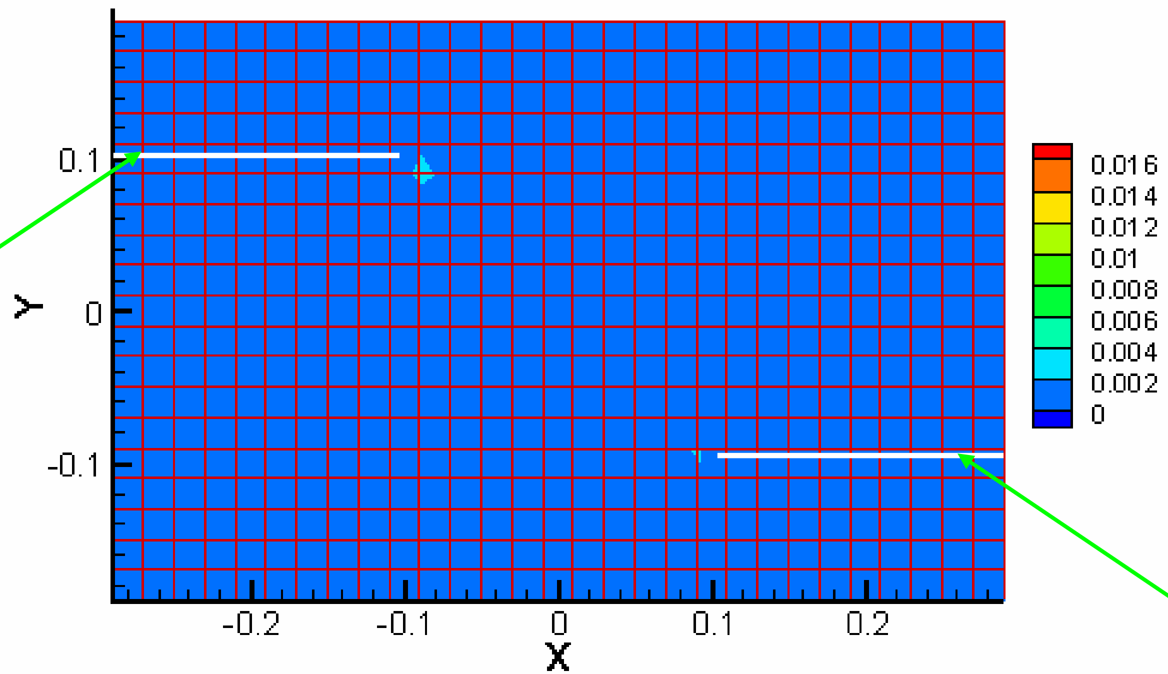
Significant variance in crack paths due to local heterogeneity

Quantitative discussion
We are going to look at PDF of crack paths



Probability Density Function of Crack Path

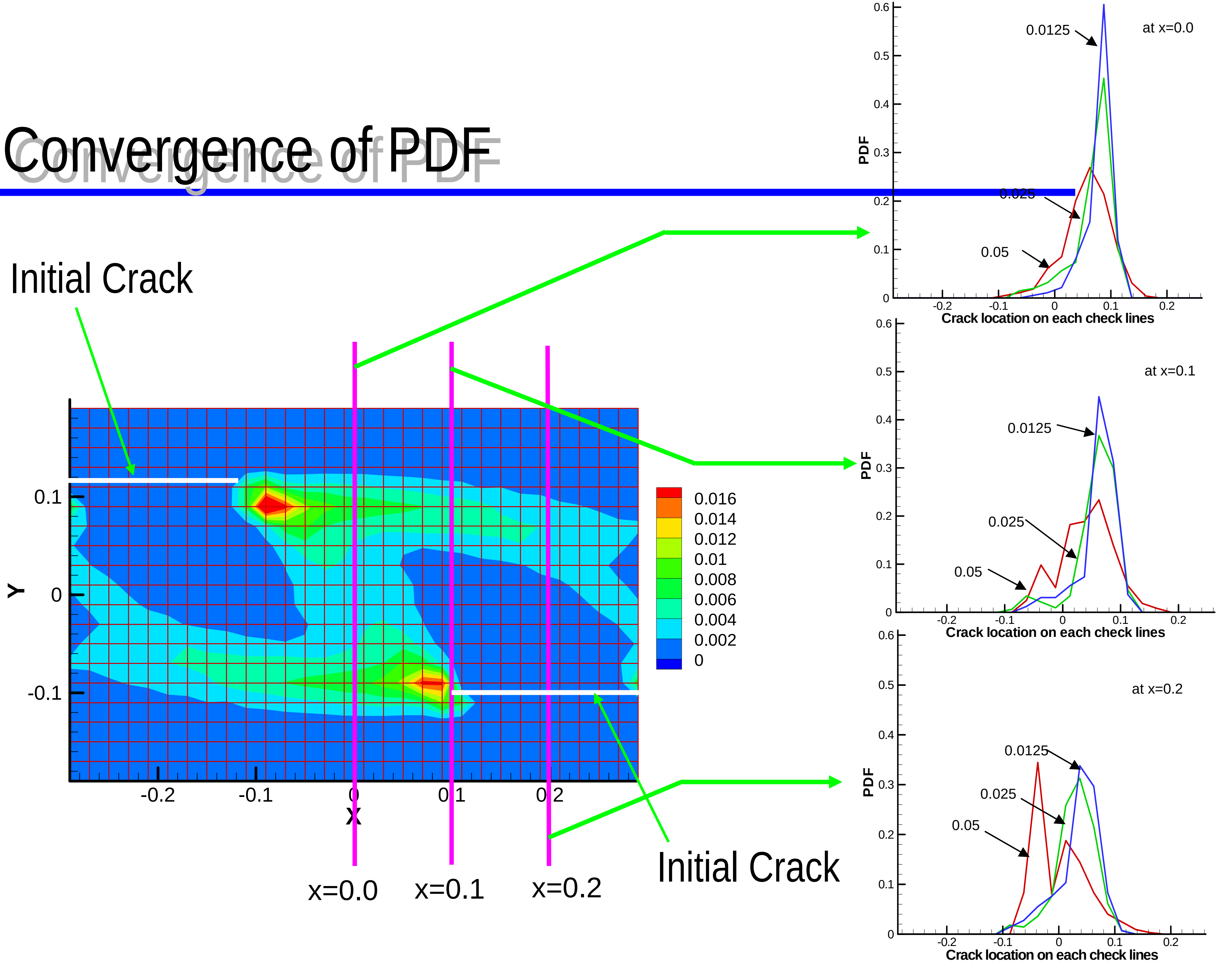
Please click it.



Initial Crack

Initial Crack

Convergence of PDF



Summary

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- Importance of local heterogeneity in analysis of failure phenomena
- Monte-Carlo simulation of crack propagation in heterogeneous bodies with different distribution of material strength
- Easy treatment of failure is needed --- FEM-β
- Wide variety of crack paths, PDF for crack paths

Gains and Losses of FEM-b

- What we got…rigorous formulation + easy treatment of failure
  - Simple treatment of failure like DEM（Strength of Material）
  - No change in Geometry/Configuration
  - Particle physics type simulation ⇒ suitable for parallel, massive computation
  - Easy treatment of local heterogeneity

- What we sacrifice…fracture mechanics, local convergence
  - Candidate for crack path is pre-determined when a mesh is made
  - （Crack surface＝Cavity） ⇒ Blunt Crack
  - Solution does not converge to the exact solution for the problem of crack growth in ideally homogeneous body