FEM simulation of fatigue damage, crack nucleation and growth in a pre-damaged material

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The ways for modeling the crack growth using finite element approach:

A model with an operative reorganization of a finite element grid during the crack extension

A model with a fixed finite element grid during the crack extension

A model with a fixed finite element grid during the crack extensions

The crack initiation and propagation is modeled based solely on assumption that the damage accumulation in material elements controls the process. Fatigue process is modeled by the sequence of damage accumulation in FE's using the Palmgren-Miner rule:

$$d = \sum_i (n_i / N_i)$$

where d - is the accumulated damage in an element, $n_i = n(S_i)$ - is the number of load cycles with the stress range S_i , $N_i = N(S_i)$ - is the number of cycles prior to failure of the "i" element with the stress range S_i.

A model with a fixed finite element grid during the crack extensions

The fatigue properties of the "material structure elements",

$N_i = N(S_i)$, are obtained from the S-N curve for the material approximated by the Basquin equation

$$N(S) = C / S^m$$

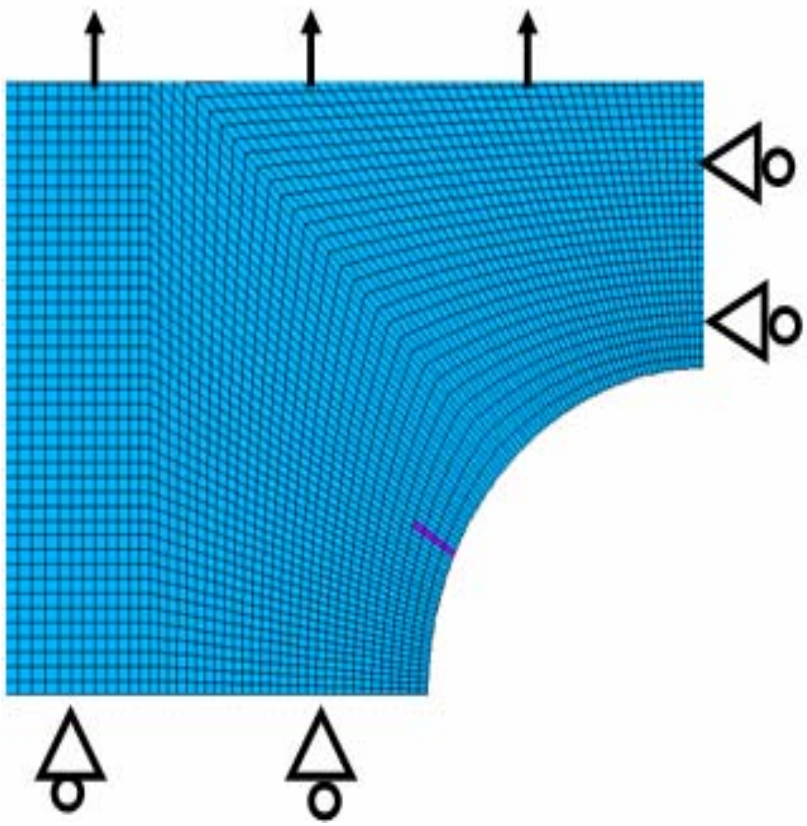
where S is the stress range, ***C*** and ***m*** are the material parameters obtained from the experimental data

Consequently, the damage accumulated in every of the elements in the course of cycling:

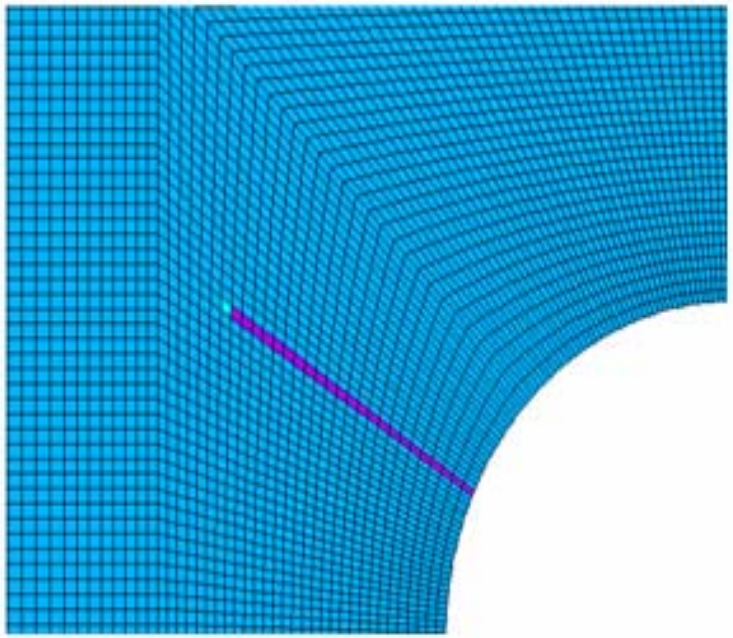
$$d = \sum_i \frac{n_i}{N_i} = (1/C)\sum_i n_i S_i^m$$

Successive failure of elements, i.e. when the damage in a sequential element becomes ***d = 1***, is defined by decreased stiffness of the element by several decimal orders (‘‘killing” of elements), and succession of failures indicates the crack extension.

The standard regular finite element mesh



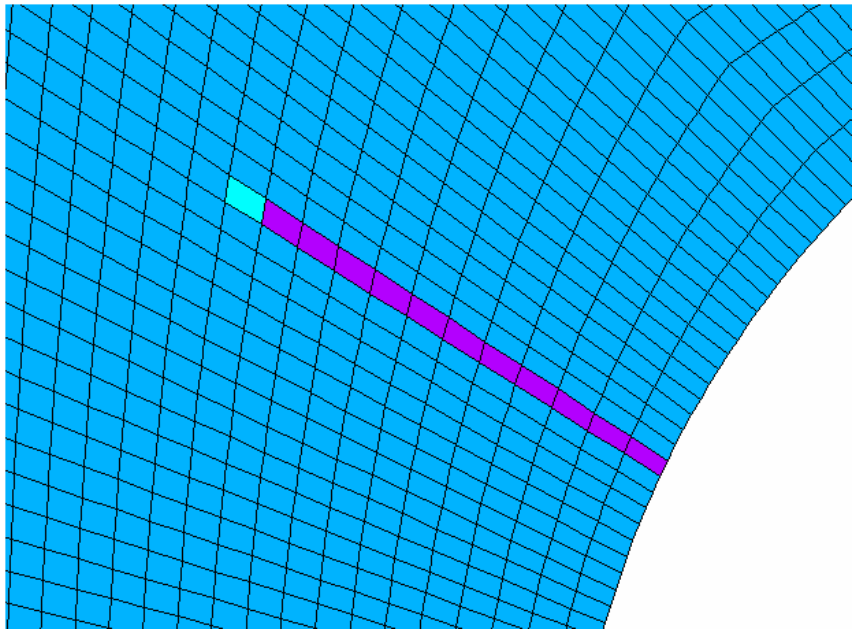
Model with initial crack



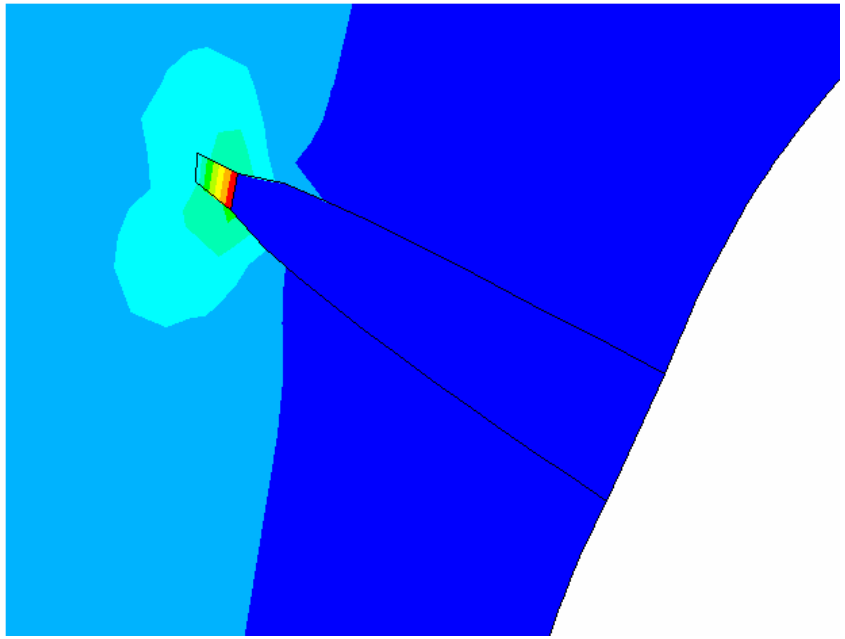
Propagation of initial crack

The crack propagation is contrary to the common sense

The standard regular finite element mesh



Finite element grid near the tip of the crack



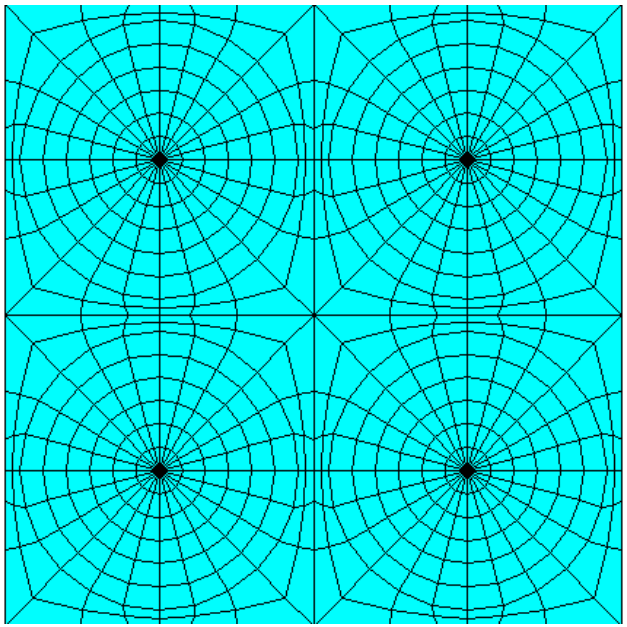
Stress intensity near the tip of the crack

<u>Conclusion:</u> every of the next damaged elements has 2 common points with the crack tip element which controls the crack path

Principles of the advanced mesh construction:

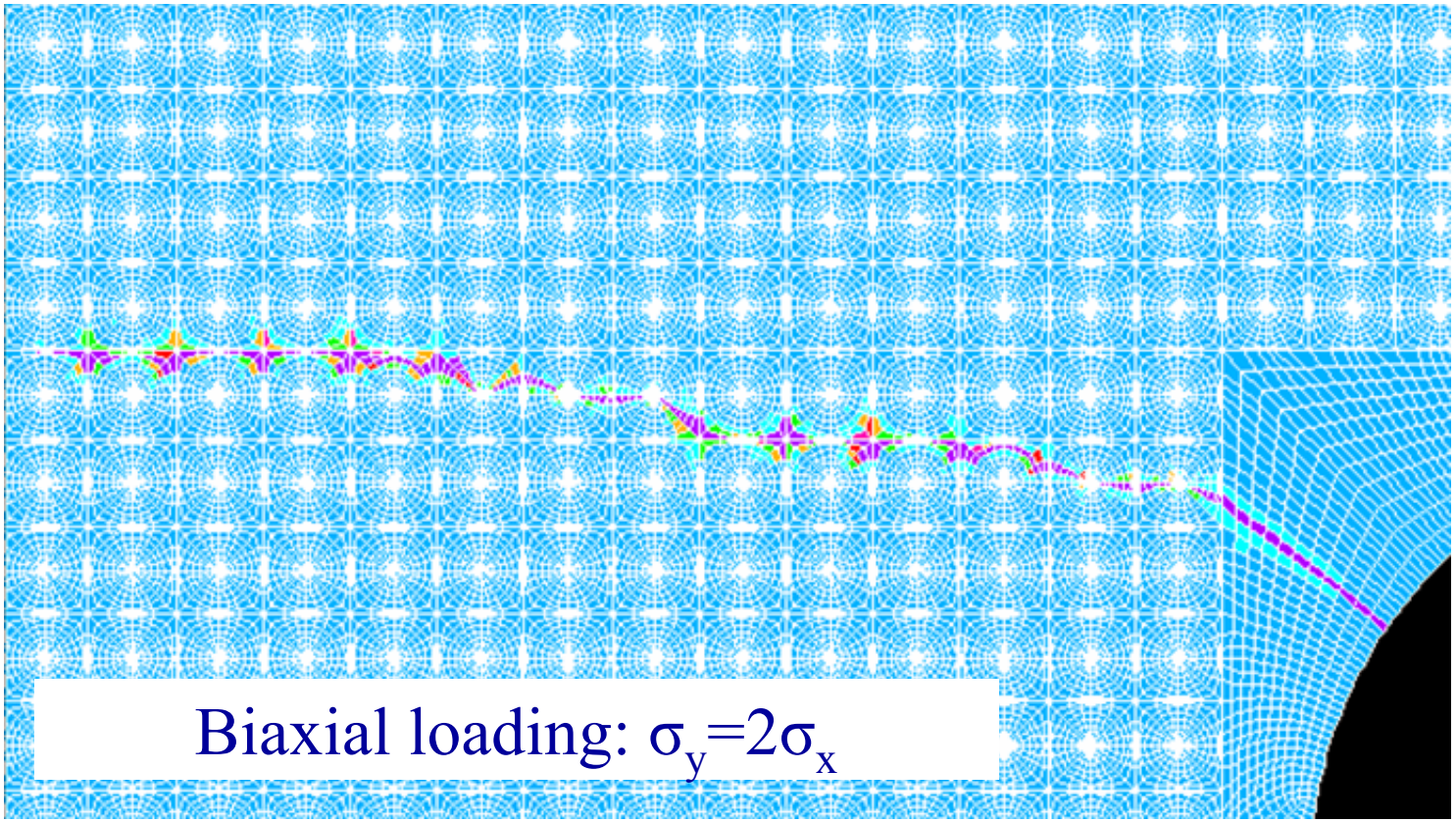
(1) The crack tip should be provided “freedom” to turn under the influence of the local stress field, accompanied by the accumulated fatigue damage in successive elements

(2) The isotropy of the grid is desired. Any specified nodal lines in the mesh would control the crack extensions.

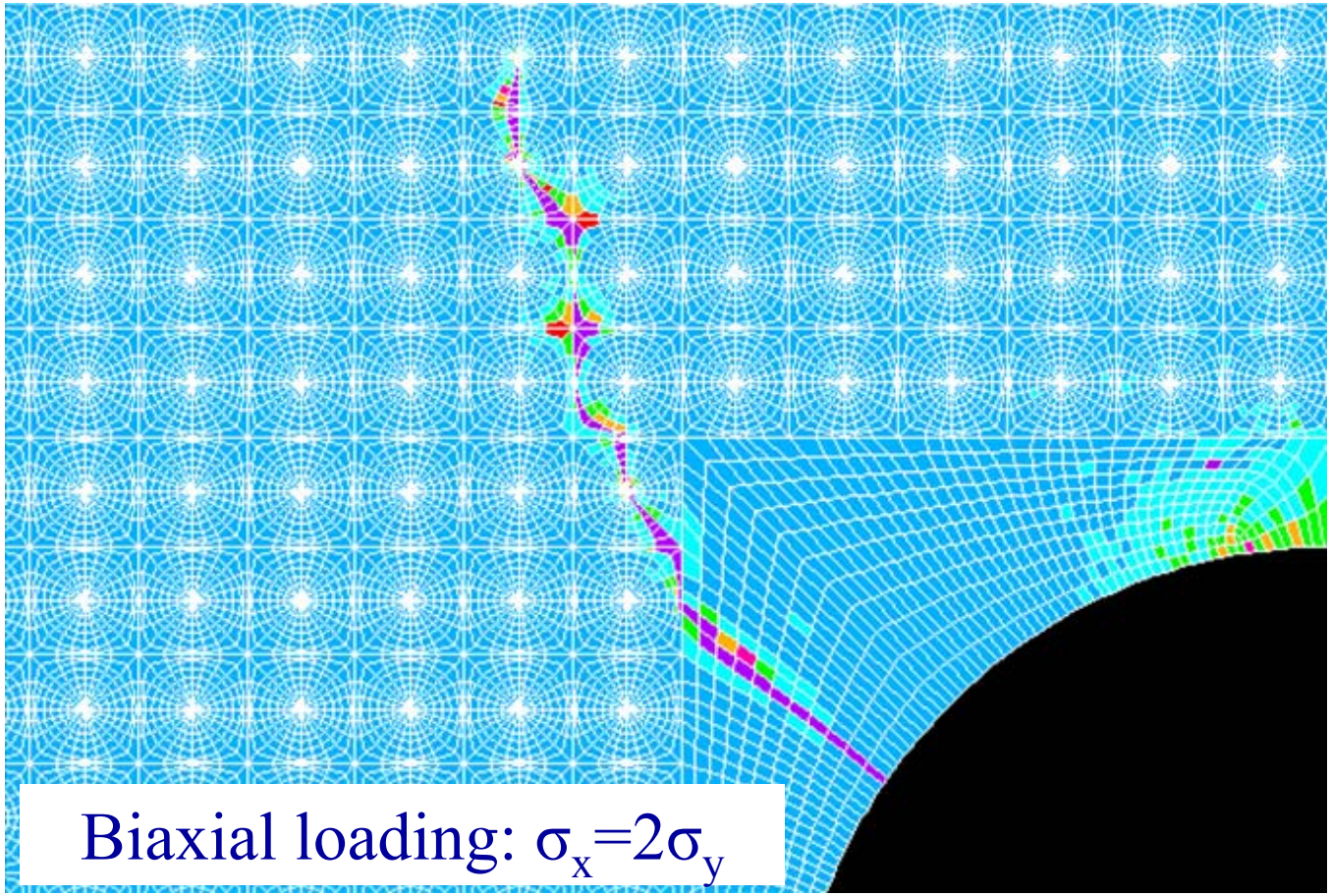


One of the examples of the advanced grid meeting the above principles

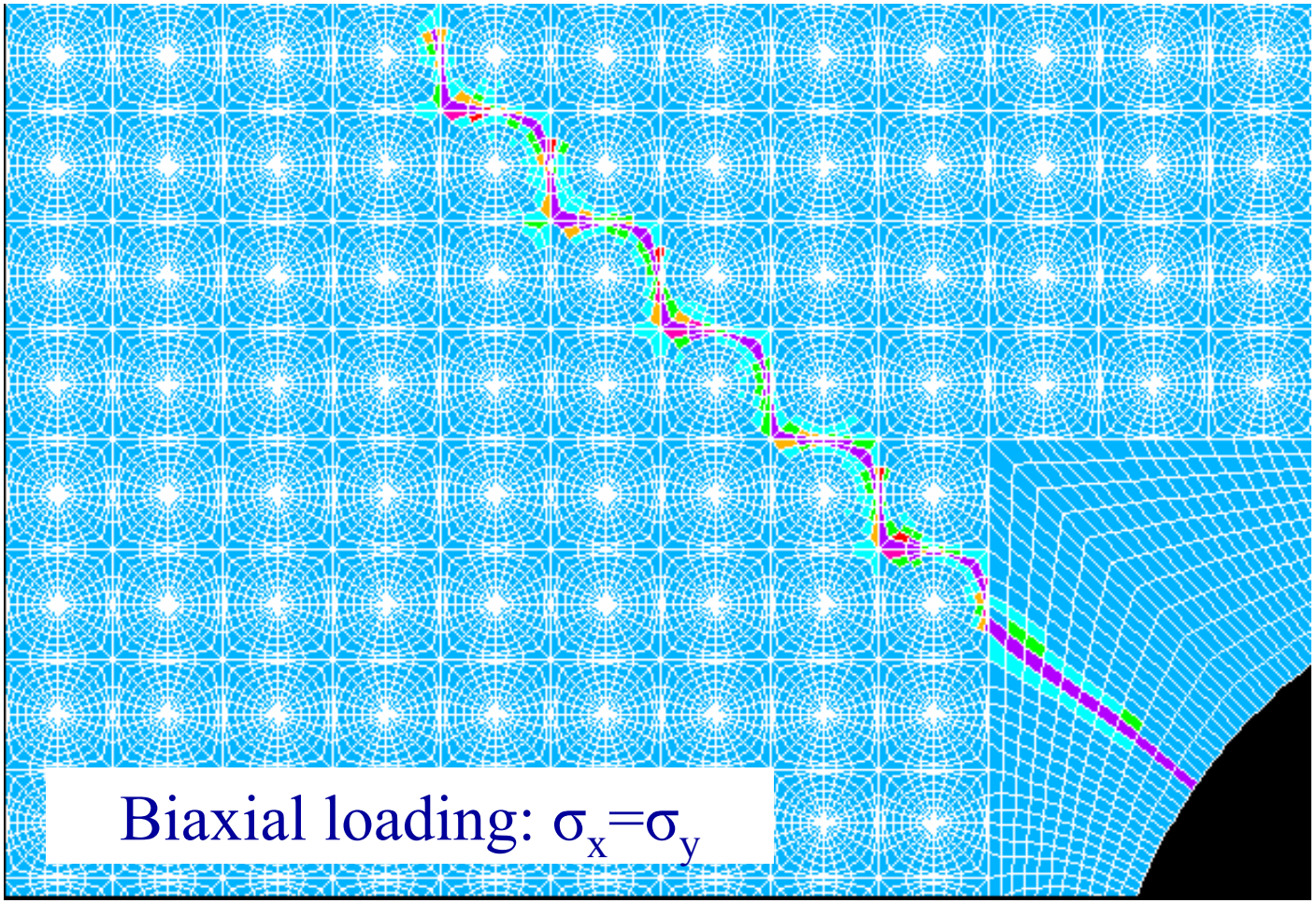
Crack behavior in the advanced mesh



Crack behavior in the advanced mesh

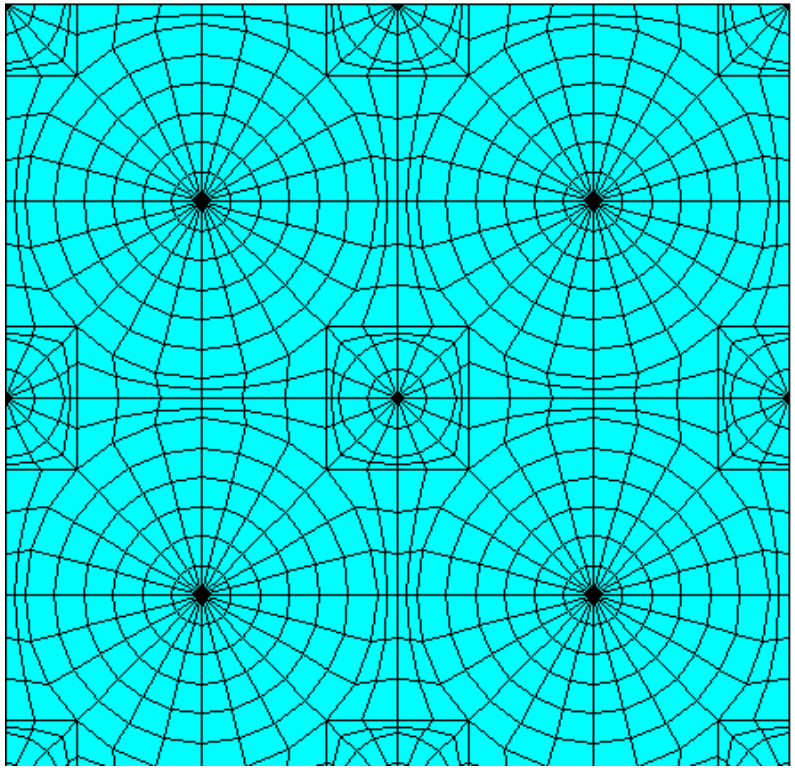


Crack behavior in the advanced mesh

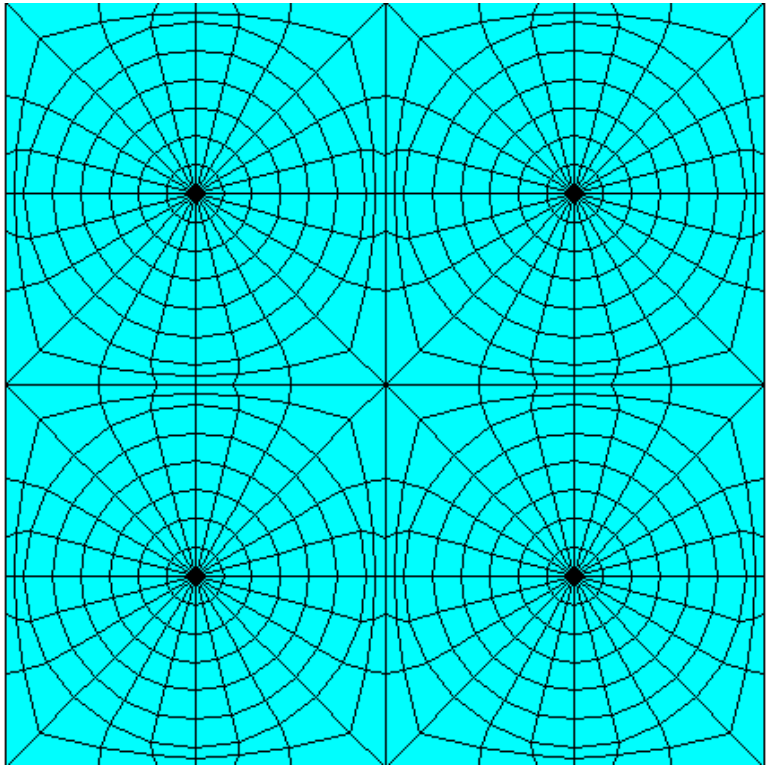


The crack path is not smooth enough

The refined 2-level mesh

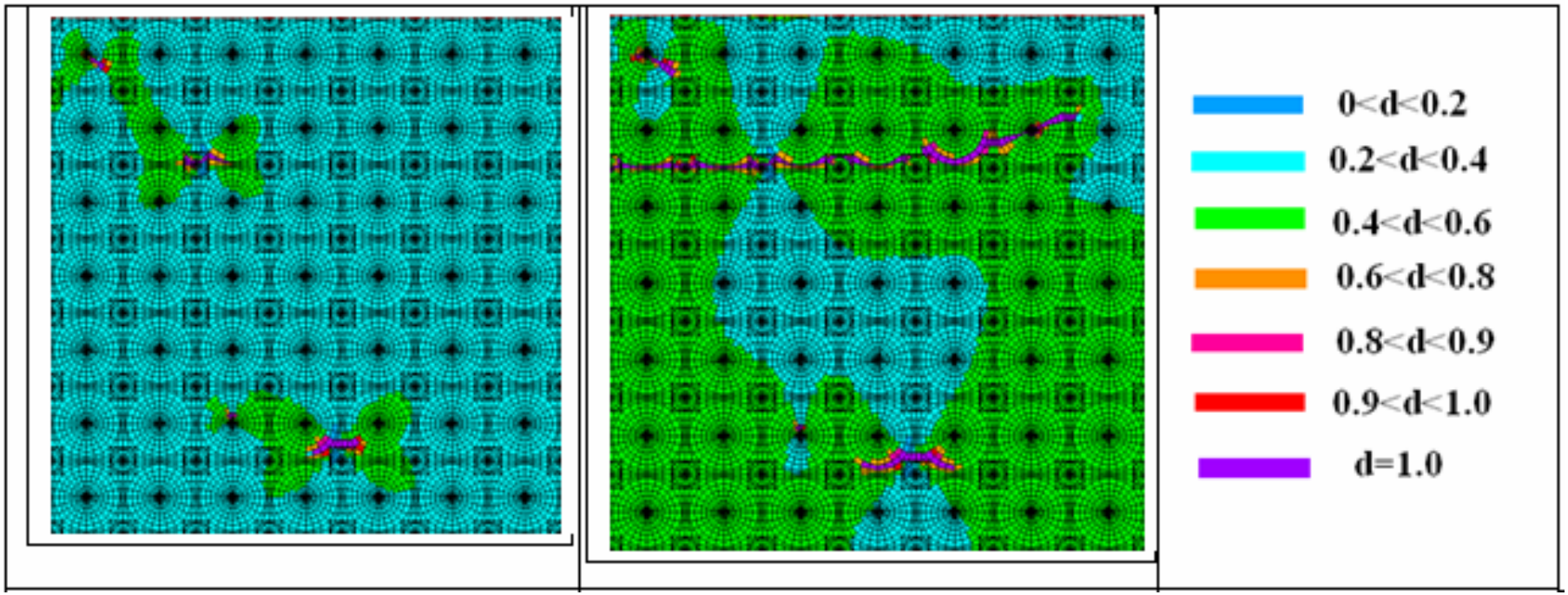


The refined 2-level mesh



The 1-level mesh

The damage accumulation and crack extension in the refined 2-level mesh

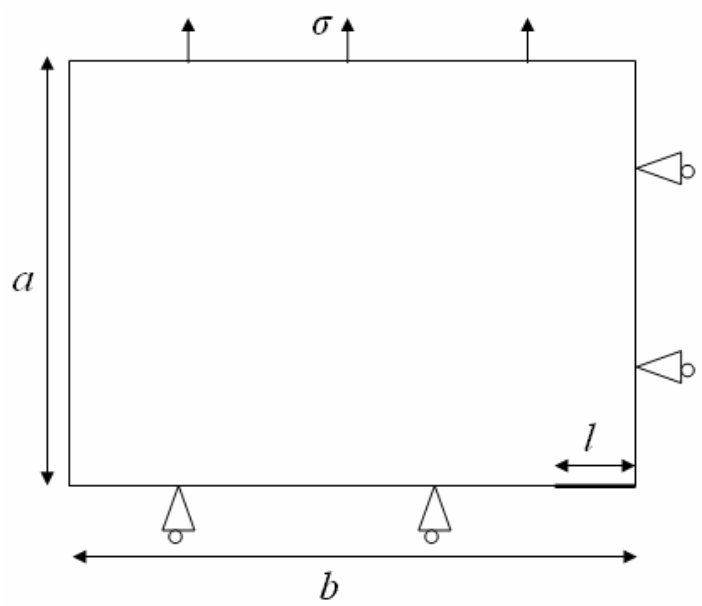


(a) initial defects;

(b) evolution of defects under cyclic loading

the damage intensity legend

The verification of the refined mesh



Base of verification:
Stress intensity factors

- when the crack is simulated using the refined mesh, K_I^{grid}
- when the regular mesh with singular elements is applied, $K_I^{\sin}$
- SIF's obtained from the hand book sources, K_I^M

The results of comparison:

- Using the refined mesh: $K_I^{grid} = 78.5\, kPa \cdot m^{1/2}$
- regular mesh with singular elements: $K_I^{\sin} = 81.6\, kPa \cdot m^{1/2}$
- Handbook data: $K_I^M = 80.3\, kPa \cdot m^{1/2}$

Conclusion:

FEM-based approaches and tools for numerical simulation of simultaneous damage and crack nucleation and evolution in media with random strength fields have been elaborated.

The approach is based on FE meshing offered which provides a realistic crack extension independent of the mesh geometry.

The fatigue crack initiation and growth in a non-uniform field of progressive fatigue damages is described based on the approach developed.

Thank you for your attention!