2007 AGU Fall Meeting: Poster #T33C-1485

Quasi-static Analysis of Strike Fault Growth in Layered Media

- Nobuki KAME*, Shuji SAITO

  Dept. of Earth and Planetary Science, Kyushu University.
- Kenji OGUNI

  Earthquake Research Institute, University of Tokyo.

1. Abstract

- *We investigate the effects of structural inhomogeneity on the growth of strike-slip fault.*
- *We adopt FEM-β, new method for failure analysis, to simulate the quasi-statistic mode III crack growth governed by the stress distribution in layered media.*
- *Our results show that along planar traces across interfaces a compliant upper layer has significant effects on promoting/suppressing crack growth before/after its extension into the layer.*
- *This proposes a possibility that surface breaks due to strike faulting could be arrested by deposit layers at the topmost part of the Earth's crust.*

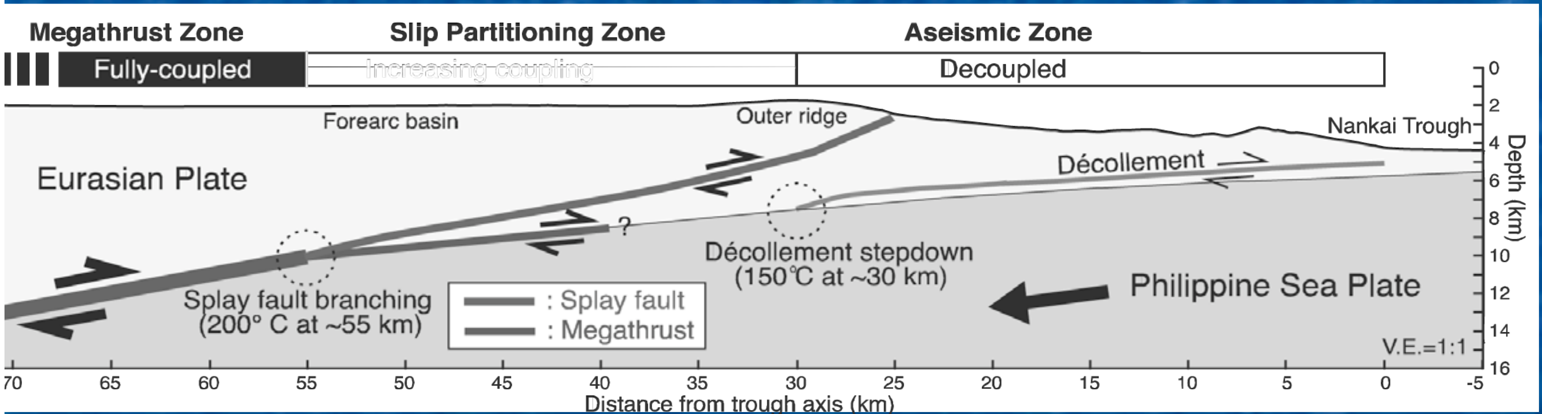
2. Motivation

- Effects of medium inhomogeneity on wave propagation

Reflection, Refraction, Surface waves, Focusing, etc…

- Effects of structural inhomogeneity on earthquake faulting

Remains unknown … Branching? Arresting??



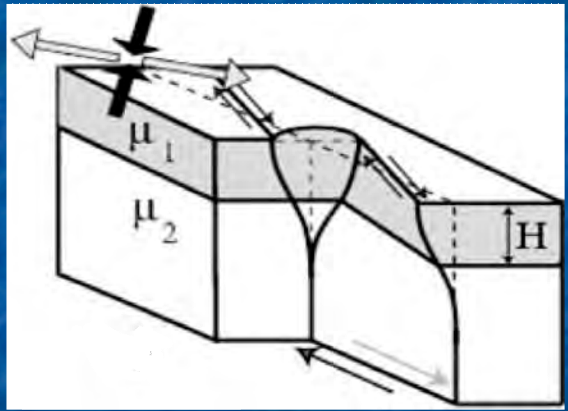


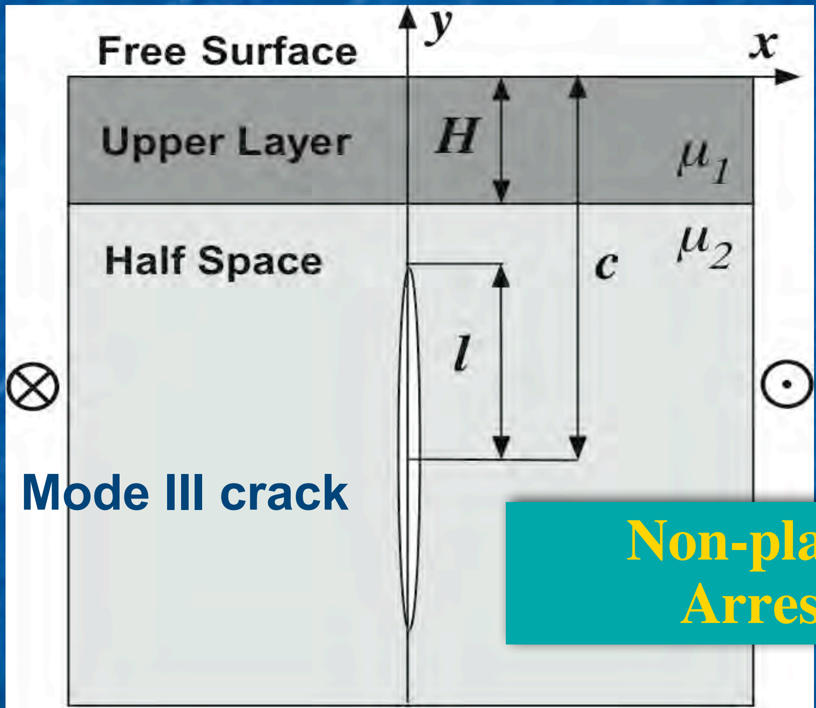
Fig.1: Schematic cross section of the updip portion of the Nankai subduction zone: splay fault branching *(Park et al., Science, 2003)*

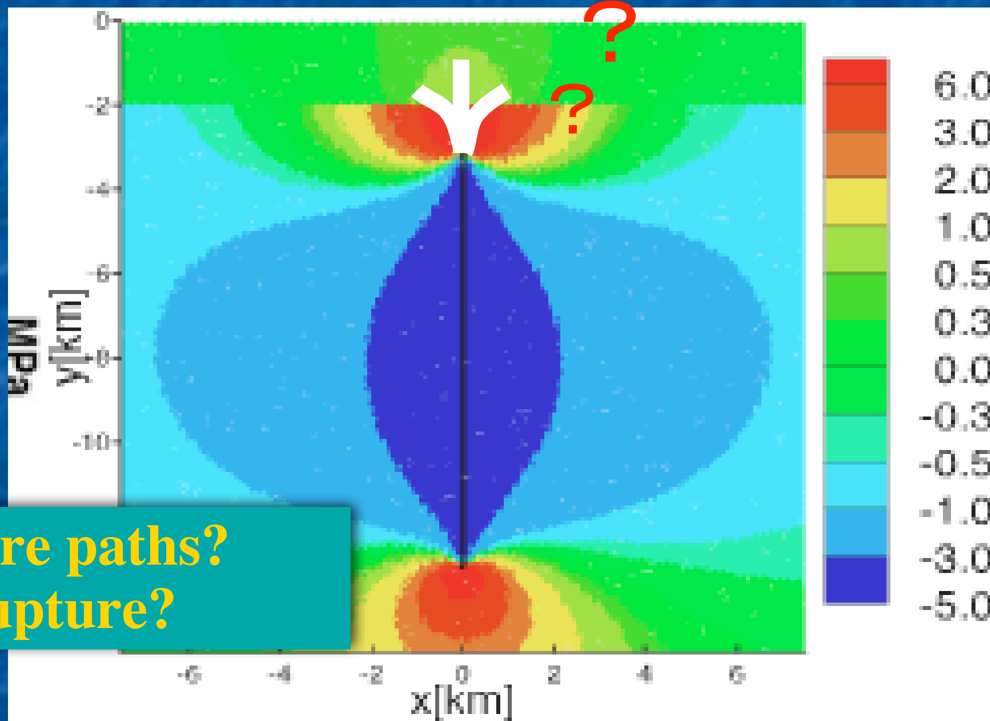
Fig.2: Possible non-planar faulting paths and en-echelon surface ruptures in a layered medium *(Bonafede et al., GJI, 2002)*

3. Model, Crack in Layered Medium

As the simplest model in the Earth's inhomogeneous crust

The stress concentration ahead of crack tip is strongly affected by the presence of inhomogeneous medium structure, which influence the process of crack propagation.





Non-planar failure paths?
Arresting of rupture?

Fig.3. Model configuration. A medium made up of upper elastic layer: $-H<y<0$ with rigidity μ_1, a free surface on $y=0$ and welded on $y=-H$ to a lower half-space: $y < -H$ with elastic parameters μ_2. A planar seed crack with the half-length l is initially embedded within half-space and c is its midpoint.

Fig.4. The stress changes $\Delta\sigma_{xz}$ induced by a crack with stress drop $\Delta\sigma=5.00$MPa in layered medium. Parameters are set to $H=2.00$km, $c=8.00$km, $l=5.00$km, $\mu_2=22.5$GPa. A compliant layer $\mu_1/\mu_2=1/10$ for 'model A' is assumed.

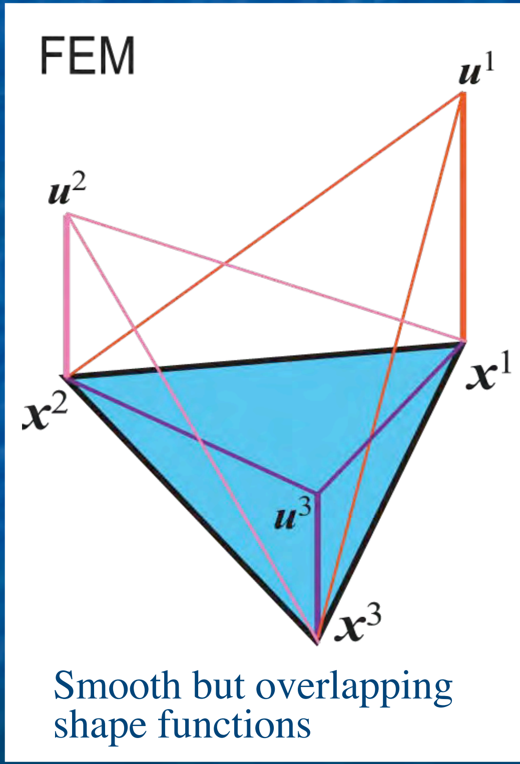
4. Failure Analysis in Layered Medium

FEM-β: Finite Elemant Method w/particle discritization (Hori et al., 2005)

Ordinary FEM
◎inhomogeneity
× discontinuity

FEM-β
◎inhomogeneity
◎discontinuity

Displacement on Volonoi blocks (Ω^1, Ω^2, Ω^3,…)
→ Easy expression of failure as separation of two adjacent Voronoi blocks
→ Stress evaluation is identical to ordinary FEM



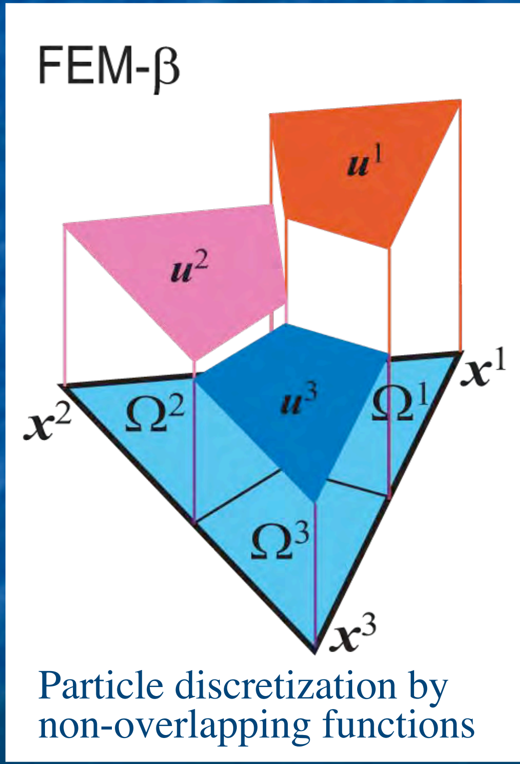


Fig.5. Comparison of discretization for ordinary FEM and FEM-β.

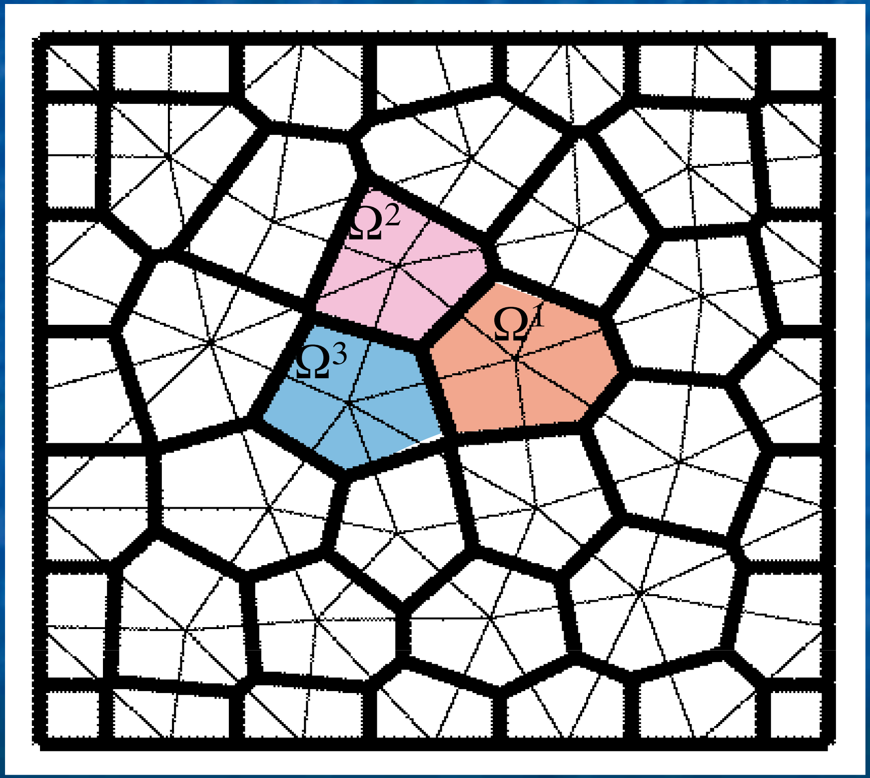


Fig.6. Voronoi (thick lines) and Delaunay (thin) tessellation for 2-D domain in FEM-β.

5. Implementation of Crack Growth

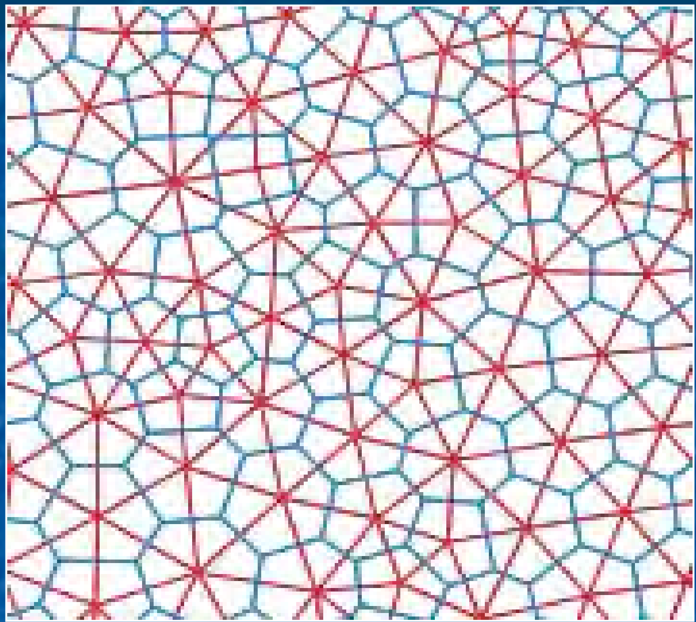


Fig.7, Stresses are calculated on all the Delaunay triangles (= finite elements)

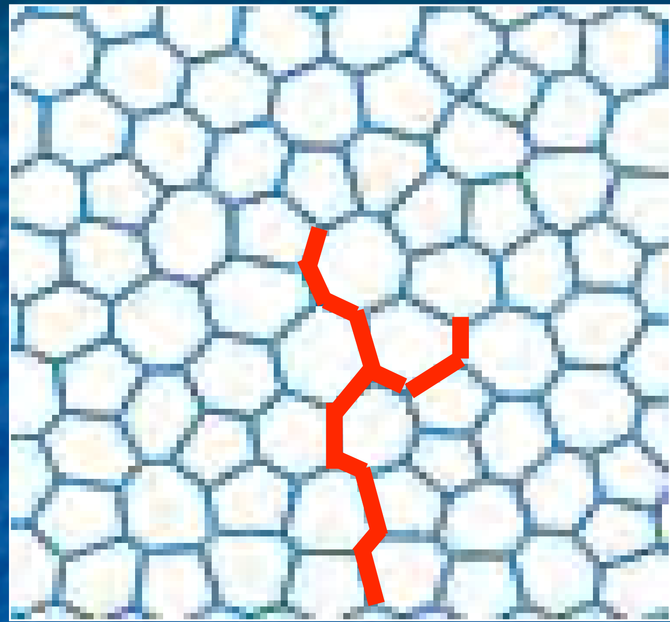


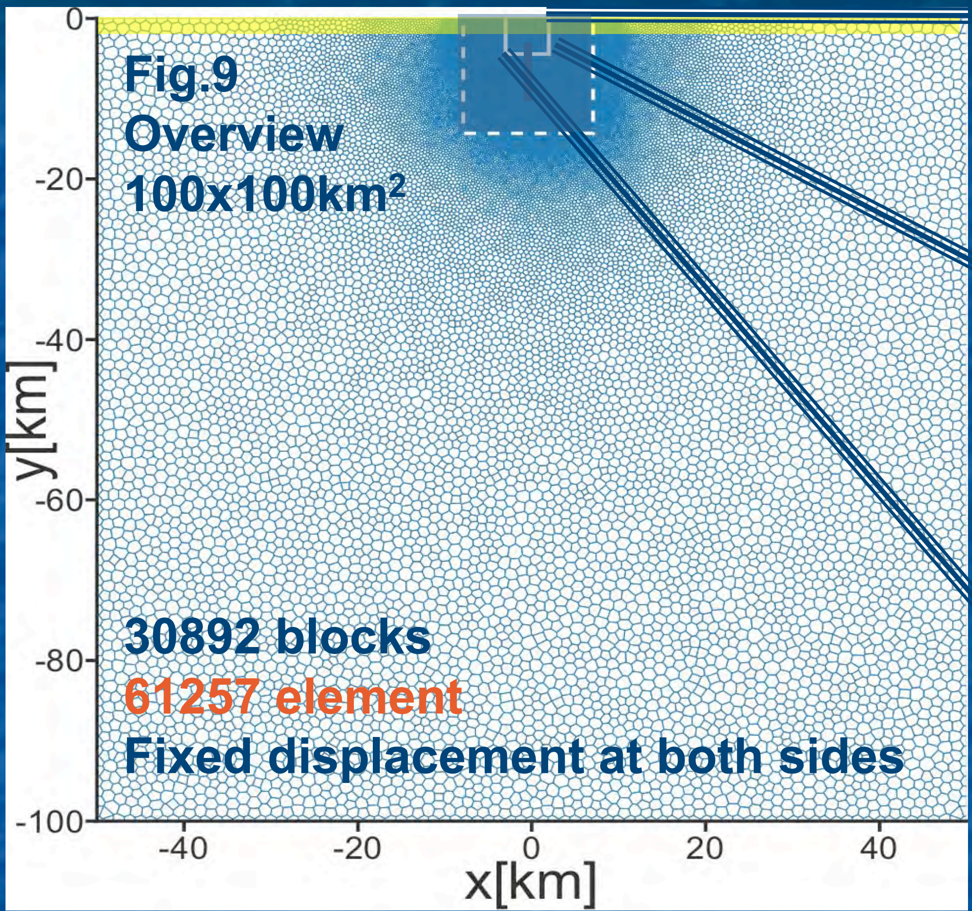
Fig.8, Failure between any two adjacent Boronoi blocks is possible.

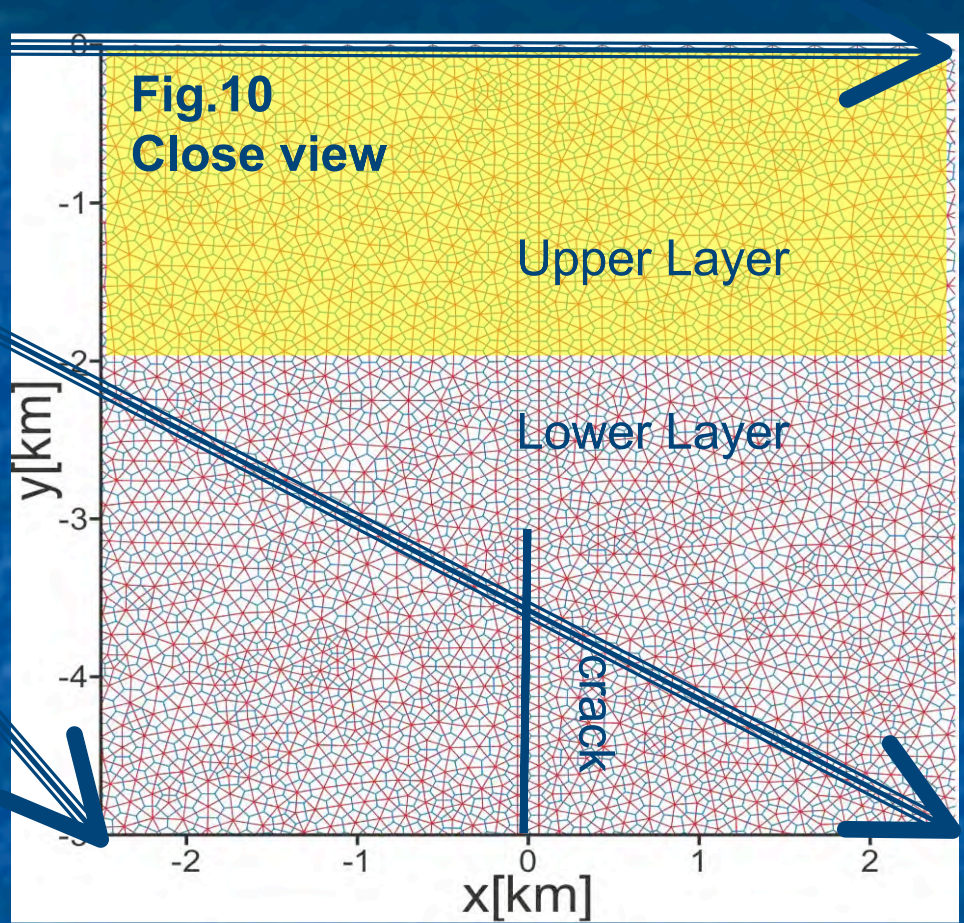
(1) Stresses on all the finite elements are evaluated.

(2) The maximum shear stress τ_{max} element is then picked up.

(3) If τ_{max} reaches threshold stress τ_{ci}, a Voronoi block interface whose normal vector is closest the maximum direction is broken (i=1,2 for upper layer and half-space). -> (1) repeated.

6. Mesh Configuration

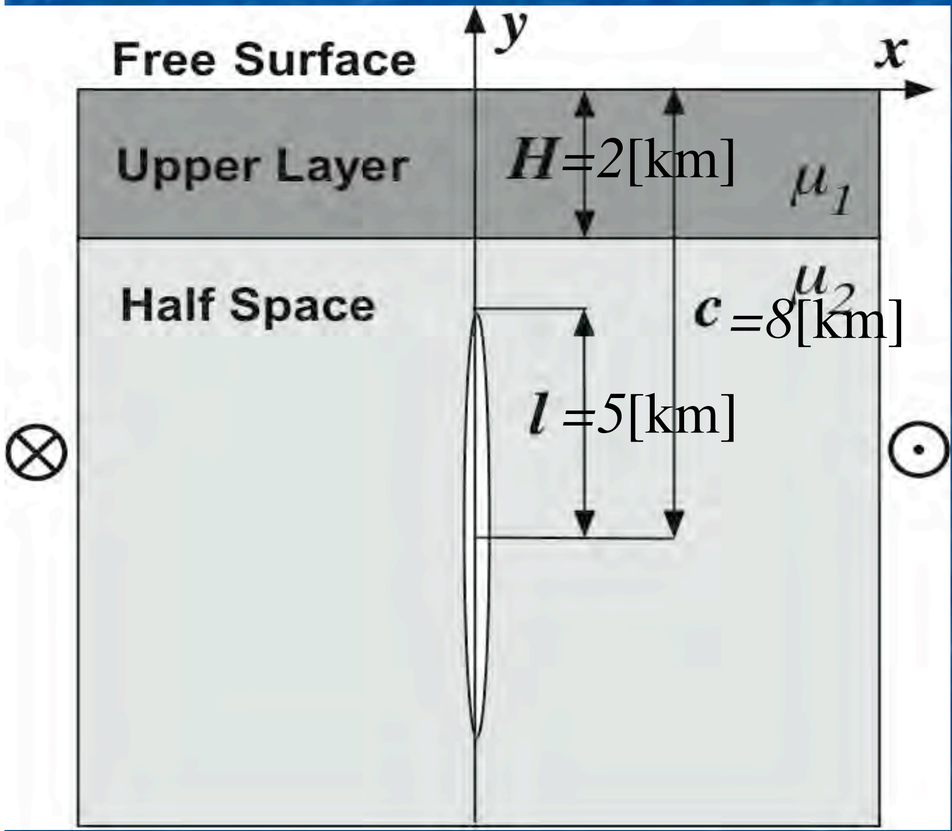




- In order to validate our simple stress criterion (it has mesh size dependency), finite elements in Fig.10 are distributed at even intervals along the layers and the initial crack plane.

7. Parameters

As well as the rigidity ratio μ_1/μ_2, the critical stress ratio τ_{c1}/τ_{c2} also affects the whole failure process



μ ratio

$\mu_1=2.25$ [GPa]

$\mu_2=22.5$ [GPa]

loading ratio

$\tau_{xz}^1=0.5$ [MPa]

$\tau_{xz}^2=5.0$ [MPa]

$\frac{1}{10}$

$\Delta\sigma$ ratio

$\Delta\sigma_1=0.5$ [MPa]

$\Delta\sigma_2=5.0$ [MPa]

$\frac{1}{10}$

Stress drop discontinuity condition

τ_{c1} critical stress ratio??

$\tau_{c1}=$?? [MPa]

$\tau_{c2}=60$ [MPa]

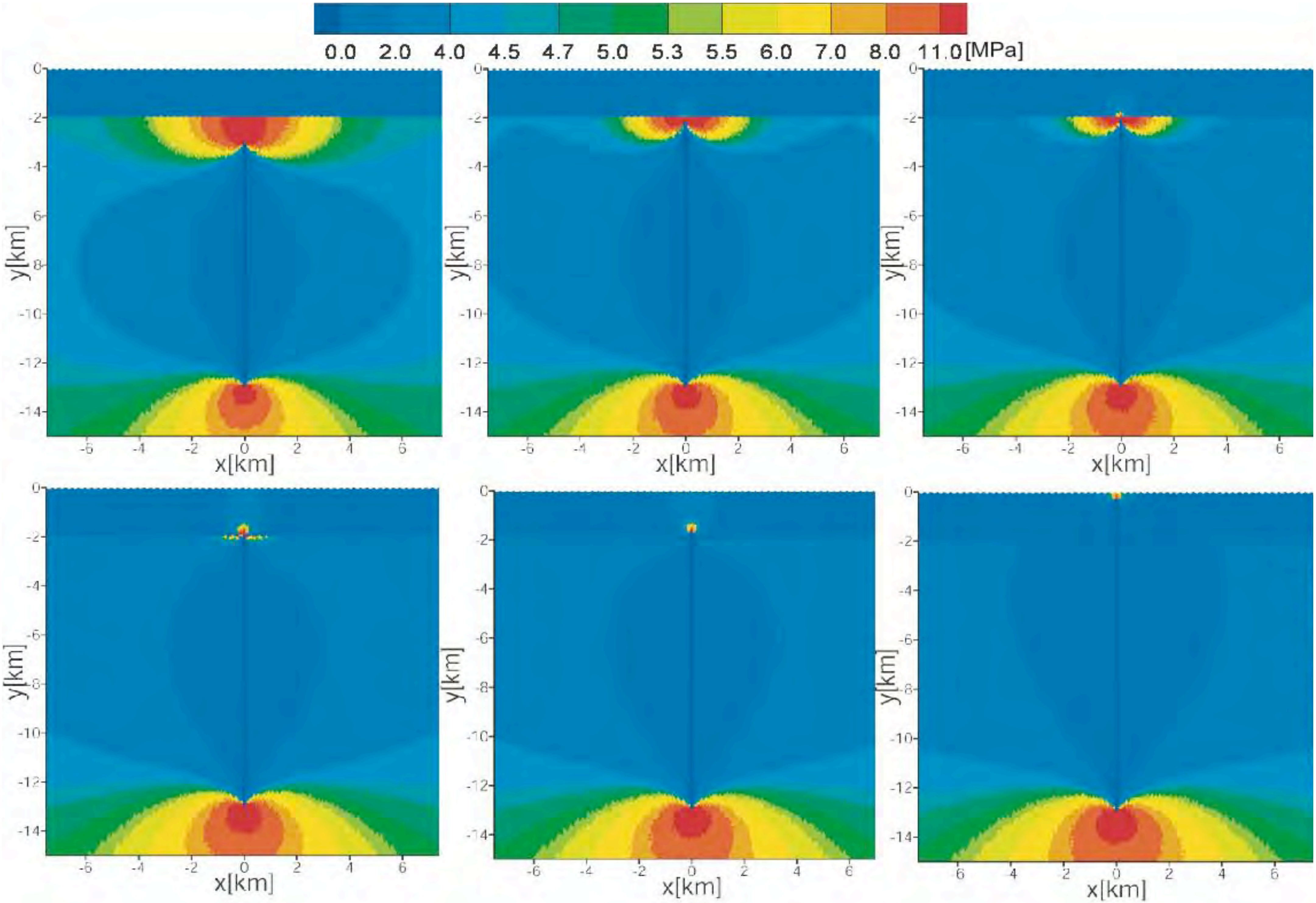
$\frac{1}{1}$ $\frac{1}{10}$

- Initial state: $\varepsilon_{xz}=const.$
- Failure path: unprescribed
- Failure criterion: $\tau_{max}>\tau_c$
- Crack surface: $\tau=0$

8. Result A, Snap Shot

- (1) Stress increases toward the interface (mirror source effect).
- (2) Planar path is formed across the interface (no non-planar failure).
- (3) Then stress decreases, but turns to increase toward the free surface.

Fig.11, Snap shots of crack growth in model ($\mu_1/\mu_2=1/10$ and $\tau_{c1}=60$MPa) with the corresponding σ_{xz} stress field. Upper crack tip locations are y=*-3.00, -2.13* and *-2.00*km from left to right in the upper row and y=*-1.88, -1.63* and *-0.25*km in the lower row, respectively.



0.0 2.0 4.0 4.5 4.7 5.0 5.3 5.5 6.0 7.0 8.0 11.0 [MPa]
y[km]
x[km]

9. Results B, Stress Evolution

Surface breaks due to strike faulting coud be arrested by deposit layers under specific assumptions of strength τ_{c1}.

- the possibility of arresting rupture ($\tau_{max} < \tau_{c1}$)

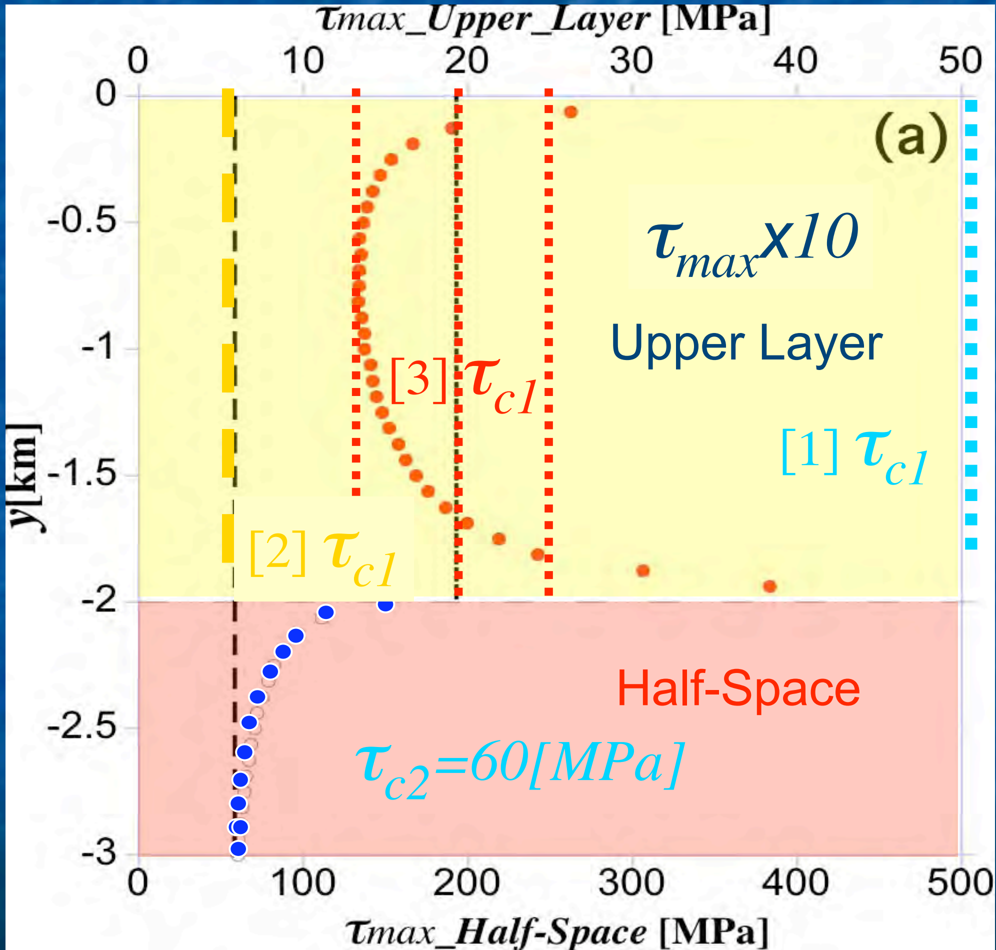


Fig.12, τ_{max} evolution with the quasi-static crack growth ($\mu 1/\mu 2=1/10$ and τ_{c1}=60MPa).

[1]stress case, $\tau_{c1} / \tau_{c2} = 1/1$

$\tau_{c1}=60$[MPa]

->Arresting at the interface

[2]strain case, $\tau_{c1} / \tau_{c2} = 1/10$

$\tau_{c1}=6$[MPa]

->Surface break

[3]intermediate case

$13 < \tau_{c1} < 60$[MPa]

->Arresting in the layer

10. Summary

- *Mode III crack growth in a layered medium is investigated.*
- *FEM-b is applied for the self-chosen failure path analysis.*
- *Planar crack path is formed across the layer interface under the stress drop discontinuity condition.*
- *A compliant upper layer has significant effects on promoting/suppressing crack growth before/after crossing the layer interface.*
- *Surface breaks due to strike faulting could be arrested by compliant sediment layers at the topmost part of the Earth's crust.*

- *Further studies:*
- *Case with inhomogeneous initial stress state*
- *Extension of FEM-β to dynamic analysis*