SIMULATING THE MECHANICS OF FRETTING FATIGUE CRACK GROWTH

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Computational Mechanics BEASY

OBJECTIVES

- Why is fretting fatigue important ?
- Accuracy of predicted contact stress
  - Comparison of numerical and analytical solution
- Fretting fatigue crack growth simulation
  - Computer model
  - Predicted crack growth path
  - Stress intensity factor solution
- Impact of crack growth on edge of contact stress
- Extension of methodology to real parts

WHY DO WE NEED TO UNDERSTAND FRETTING FATIGUE

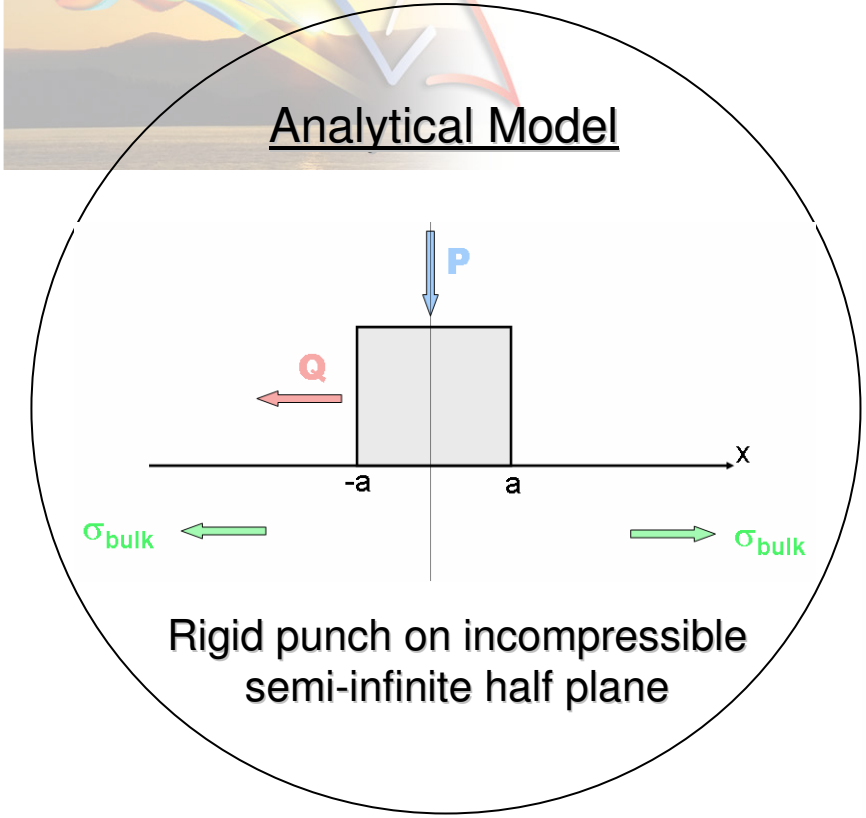
- Fretting causes wear and very high local stress near the edge of contact
- Results in crack nucleation and reduction in fatigue life of the part
- Fretting occurs in many types of contacting components subject to oscillating loads
- Recognized as one of the most costly forms of in-service damage particularly with regard to turbomachinery components

WHAT MAKES FRETTING FATIGUE DIFFICULT TO ANALYZE

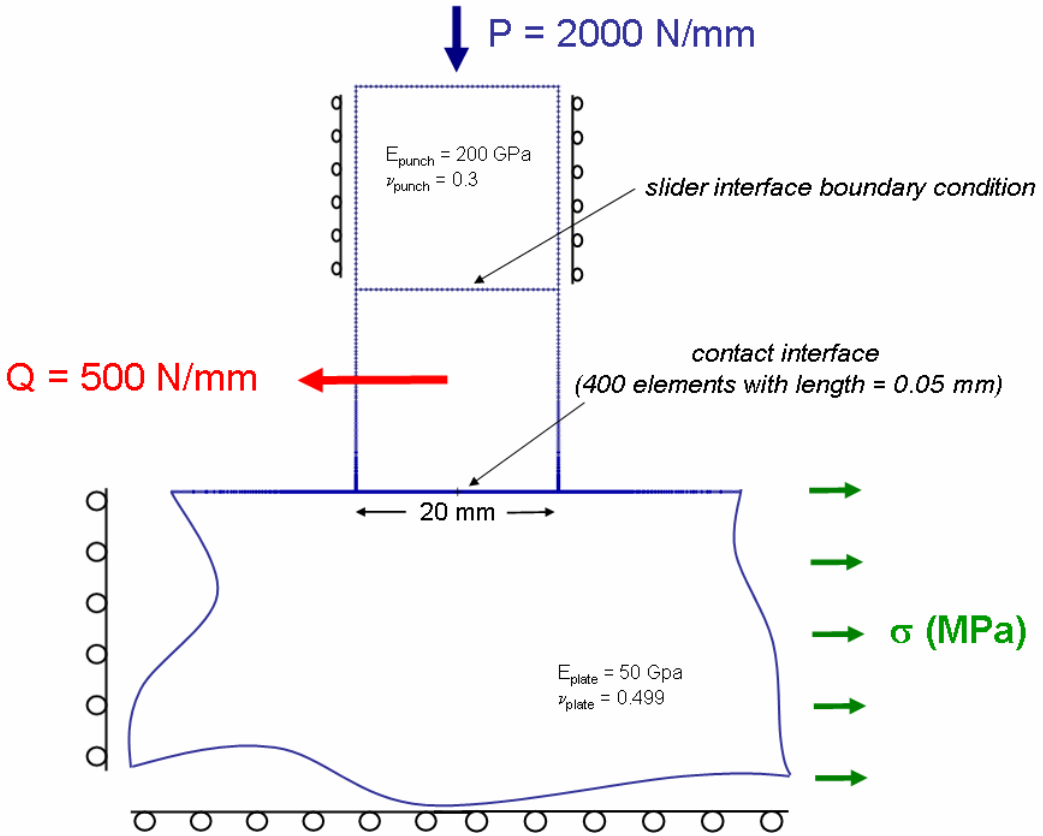
- Very high stress gradient near edge of contact
- Non-proportional loading near contact interface even with proportional applied loads
- The R-ratio (K_{min}/K_{max}) is variable as cracks grow from contact zone.
- The impact of surface damage on fatigue life, at the micromechanical level, is still not clearly understood.
- Crack growth methodology must consider length of crack *(shorts crack behave differently)*

FRETTING FATIGUE COMPUTER MODEL

Analytical Model



Rigid punch on incompressible semi-infinite half plane



COMPARISON OF NUMERICAL AND ANALYTICAL CONTACT STRESS SOLUTIONS

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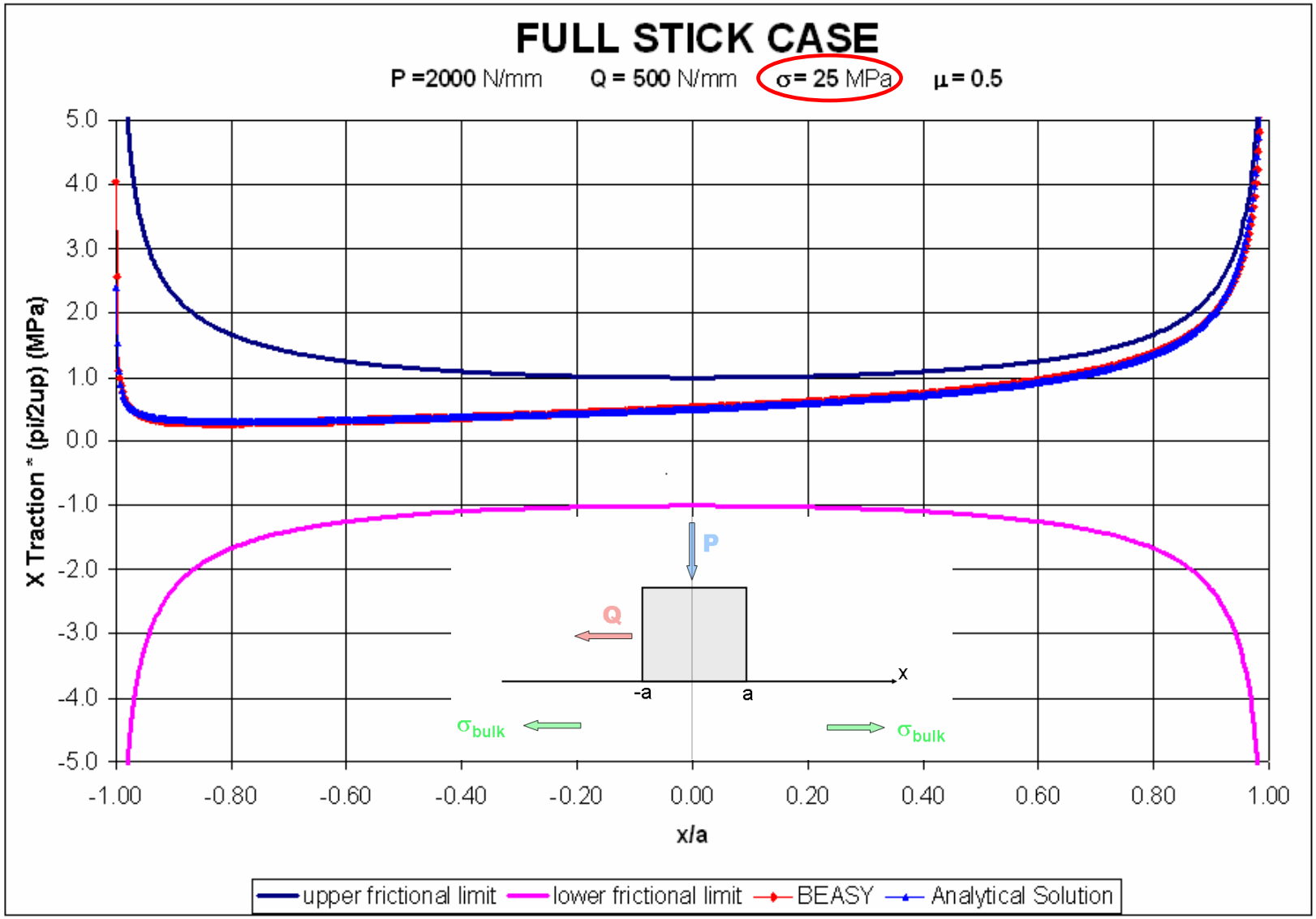
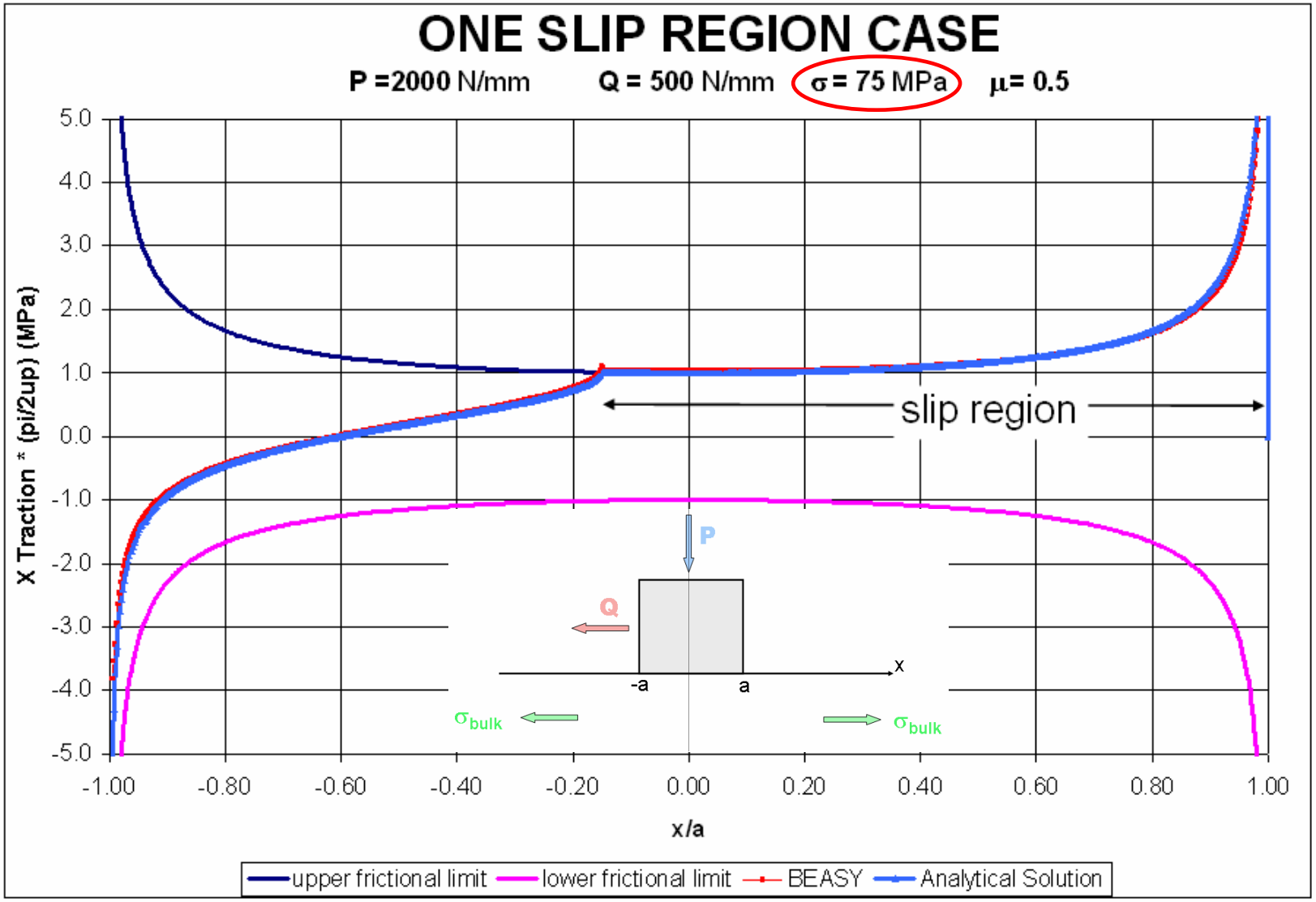
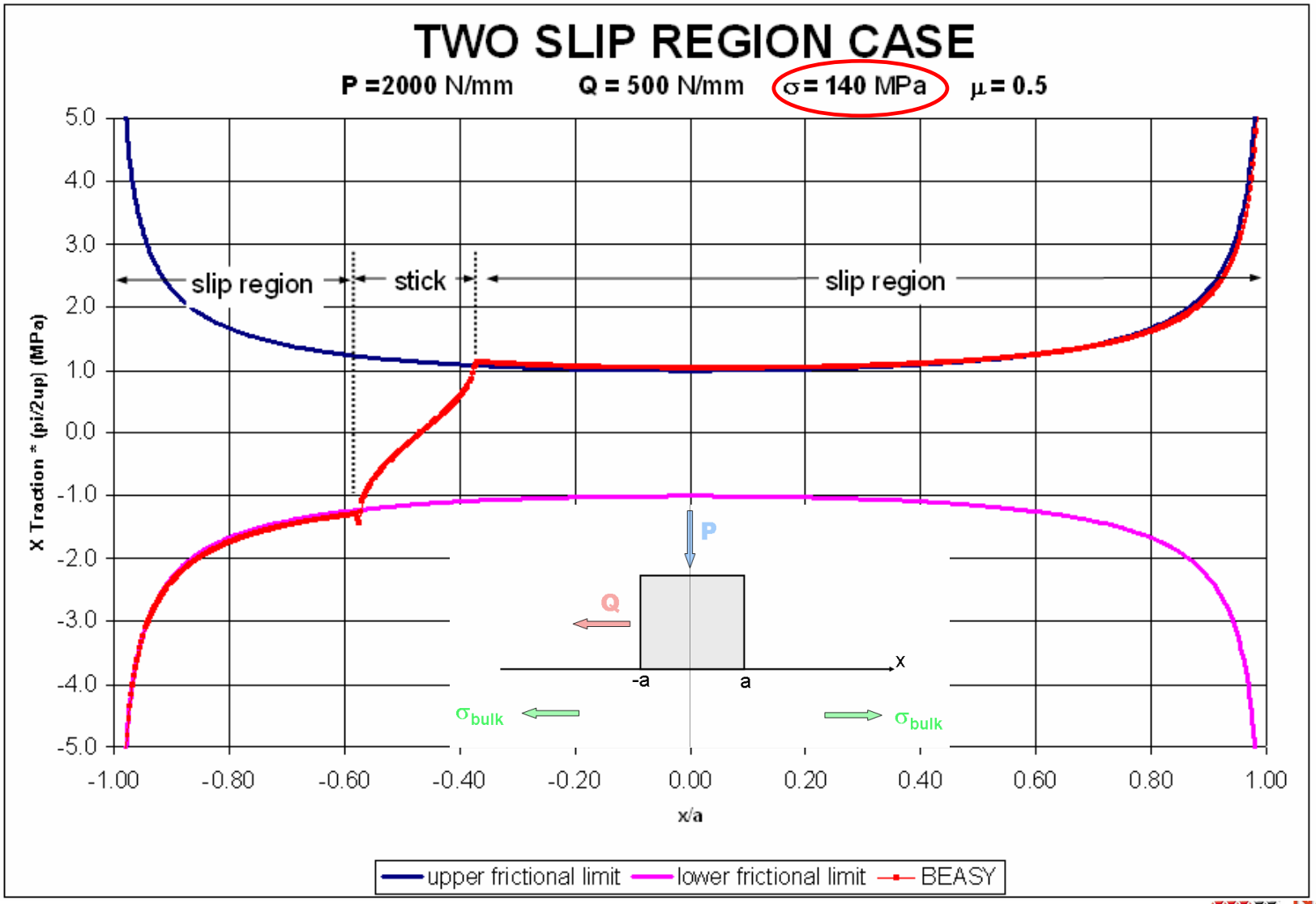
SHEAR TRACTION FOR FULL STICK CASE



SHEAR TRACTION FOR ONE SLIP REGION CASE



SHEAR TRACTION FOR TWO SLIP REGION CASE



Fretting Load Cycle Simulation

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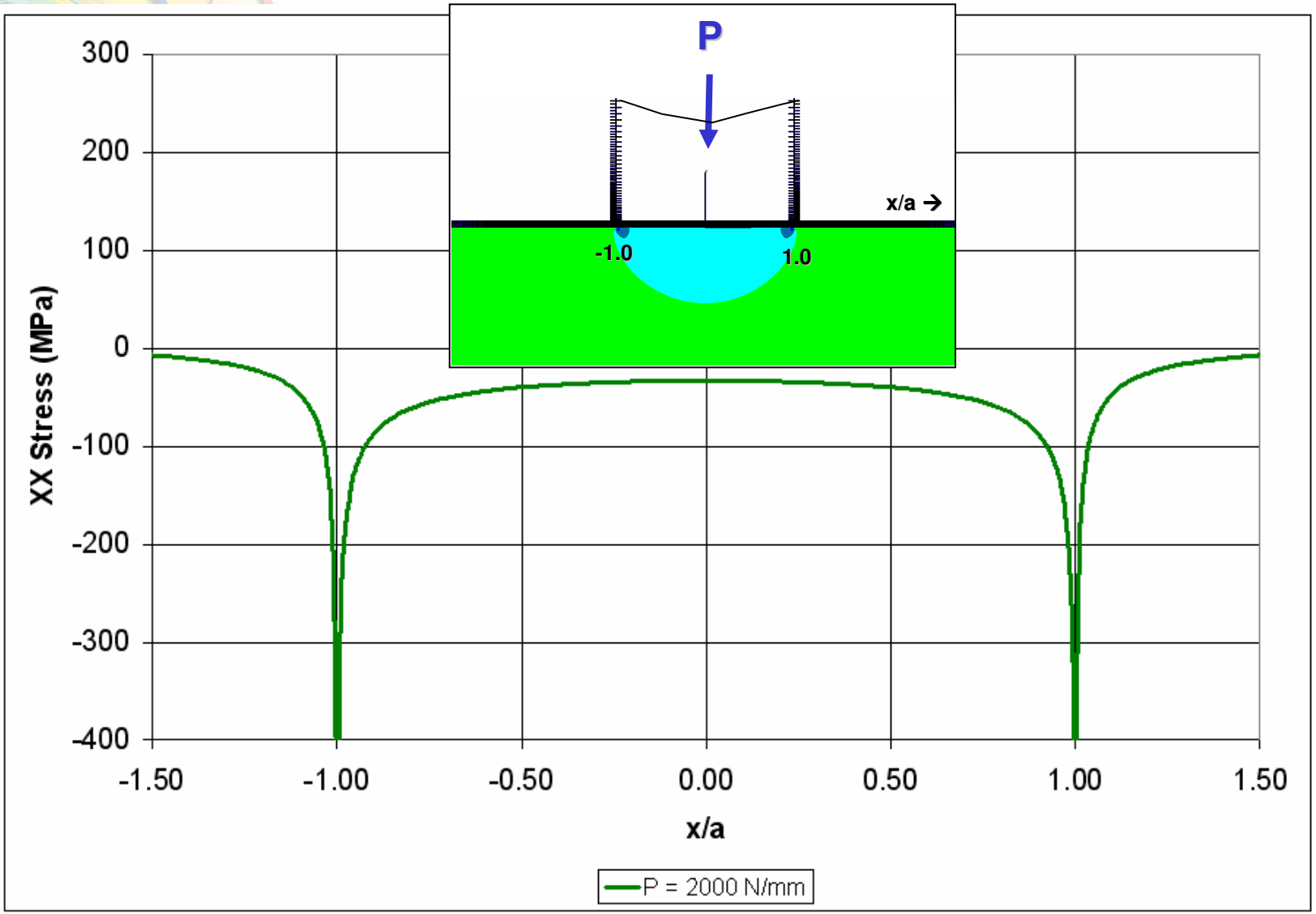
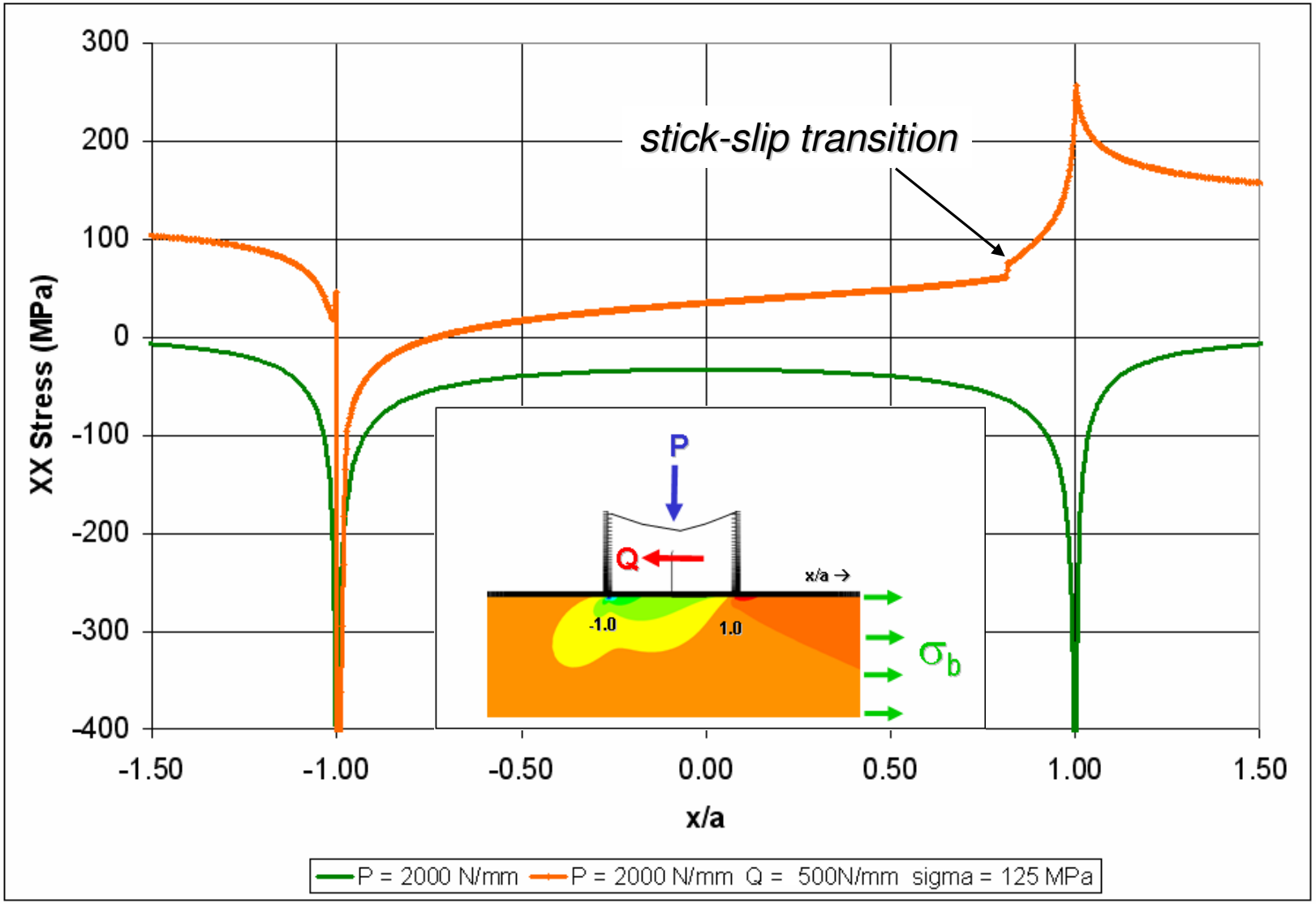
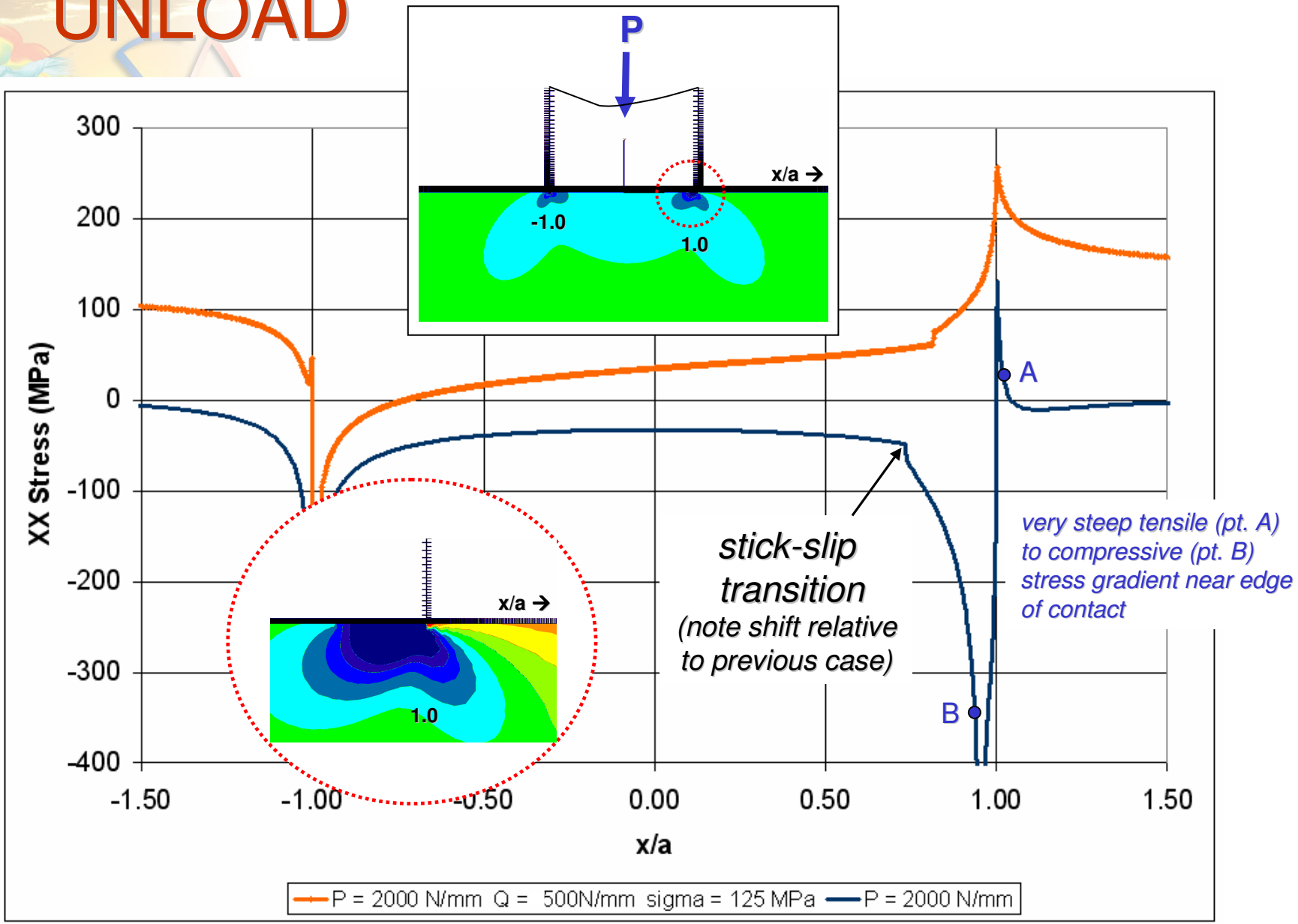
INITIAL NORMAL LOAD



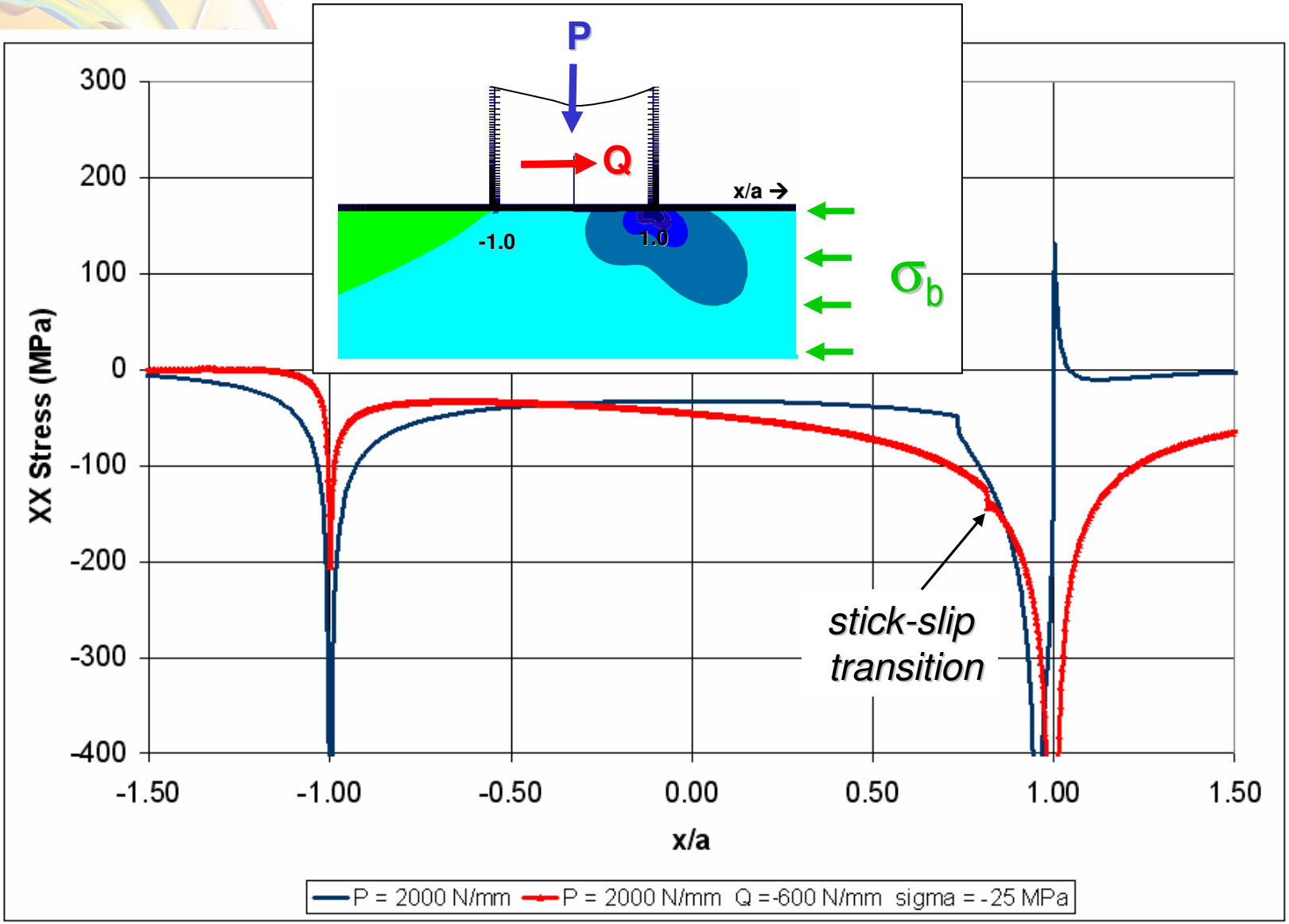
FORWARD LOAD



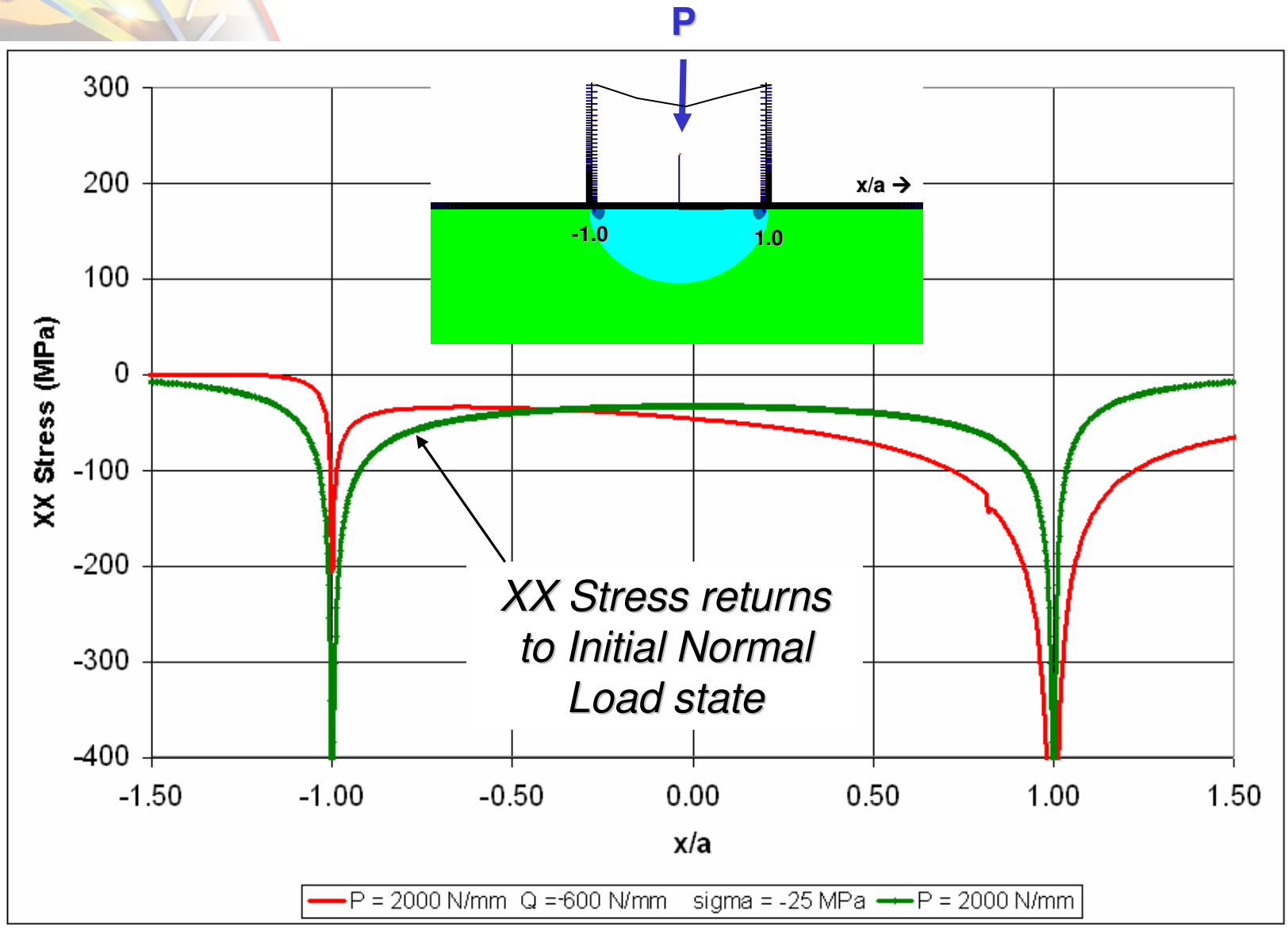
UNLOAD


P
x/a
-1.0
1.0
300
200
100
0
-100
-200
-300
-400
XX Stress (MPa)
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
x/a
A
B
stick-slip transition
(note shift relative to previous case)
very steep tensile (pt. A) to compressive (pt. B) stress gradient near edge of contact
x/a
1.0
P = 2000 N/mm Q = 500N/mm sigma = 125 MPa
P = 2000 N/mm

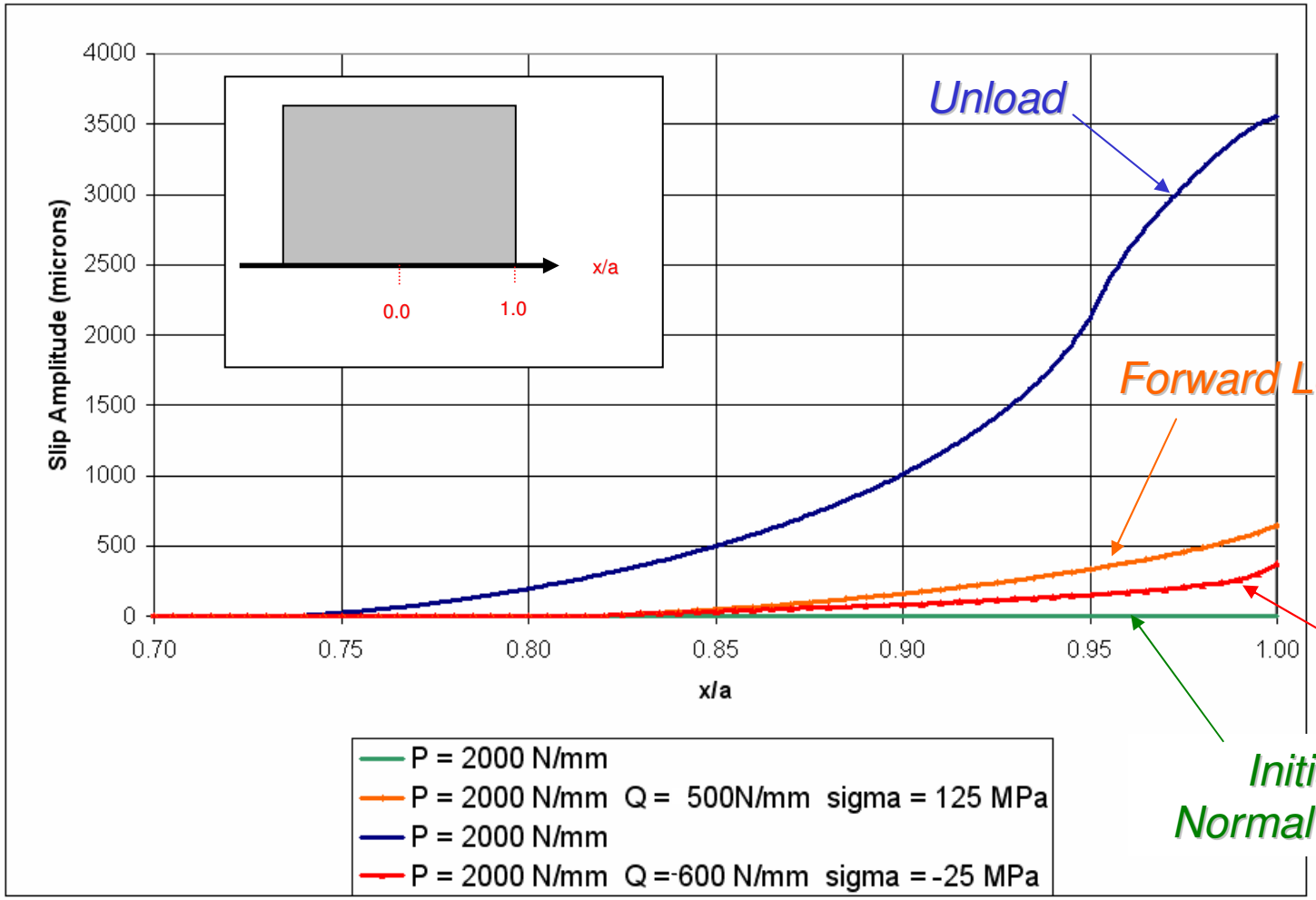
REVERSE LOAD



2nd UNLOAD


P
x/a →
-1.0
1.0
300
200
100
0
-100
-200
-300
-400
XX Stress (MPa)
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
x/a
XX Stress returns to Initial Normal Load state
P = 2000 N/mm Q =-600 N/mm sigma = -25 MPa
P = 2000 N/mm

CHANGE IN SLIP AMPLITUDE DURING FRETTING LOAD CYCLE



FRETTING FATIGUE CRACK GROWTH SIMULATION

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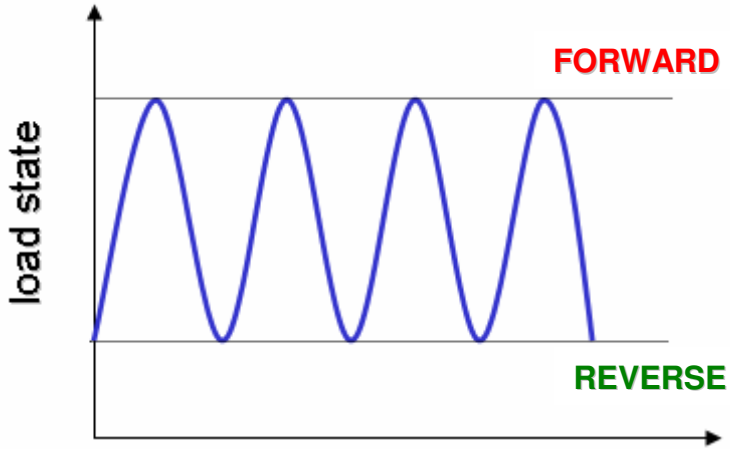
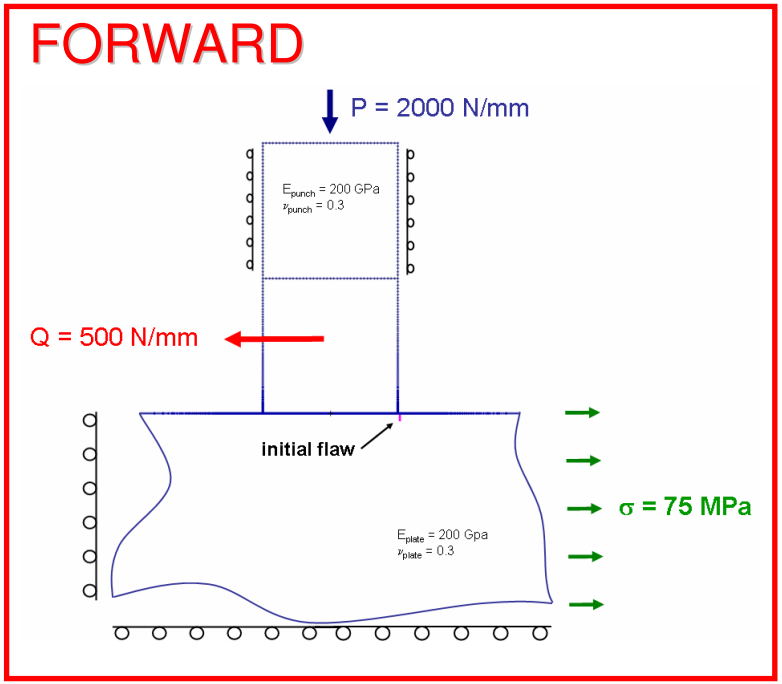
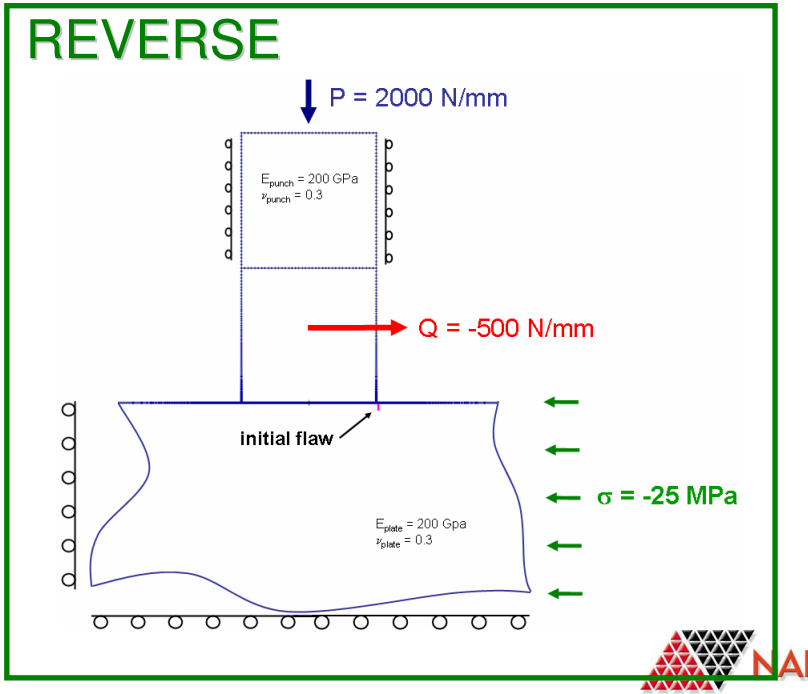
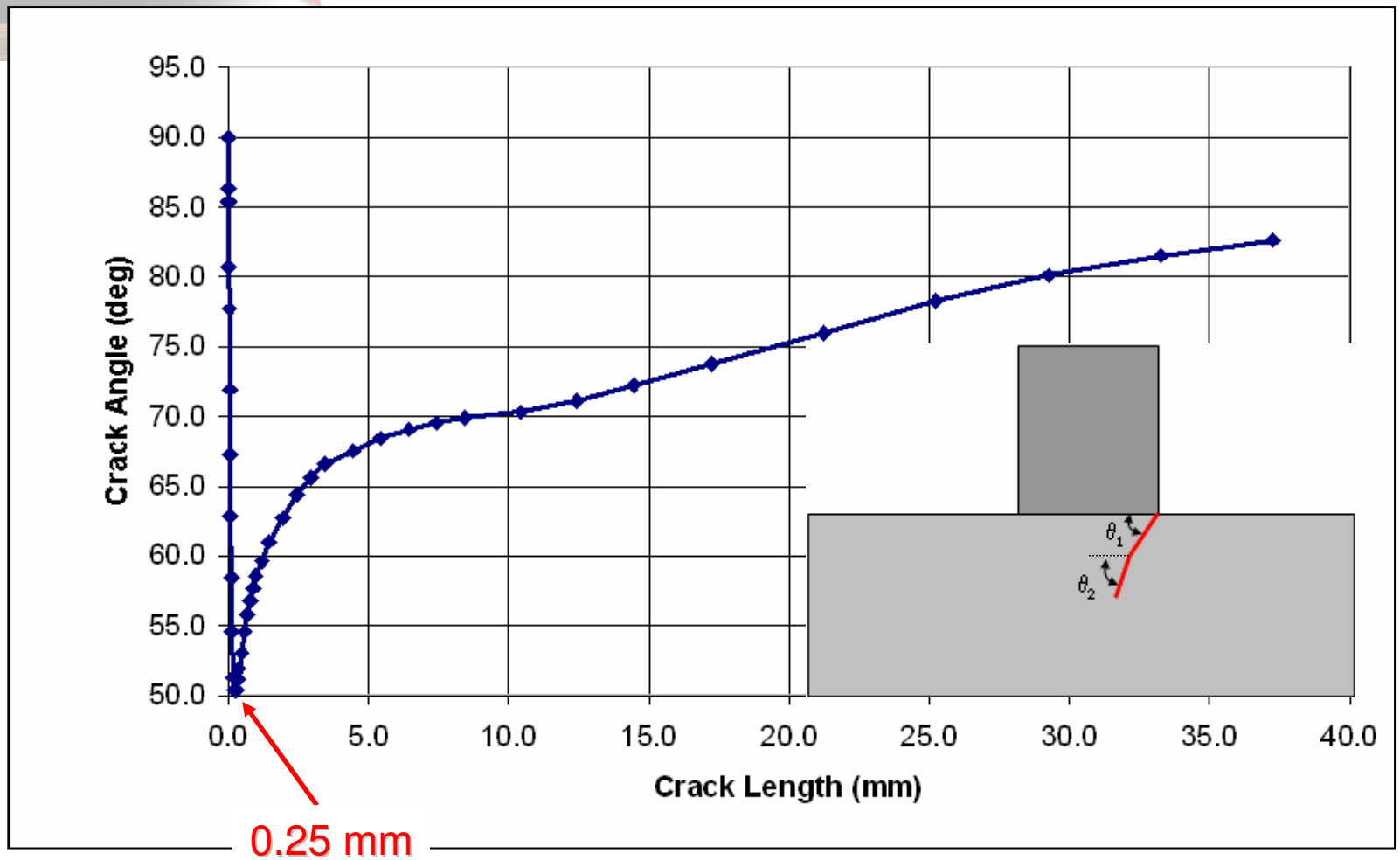
CRACK GROWTH COMPUTER MODEL



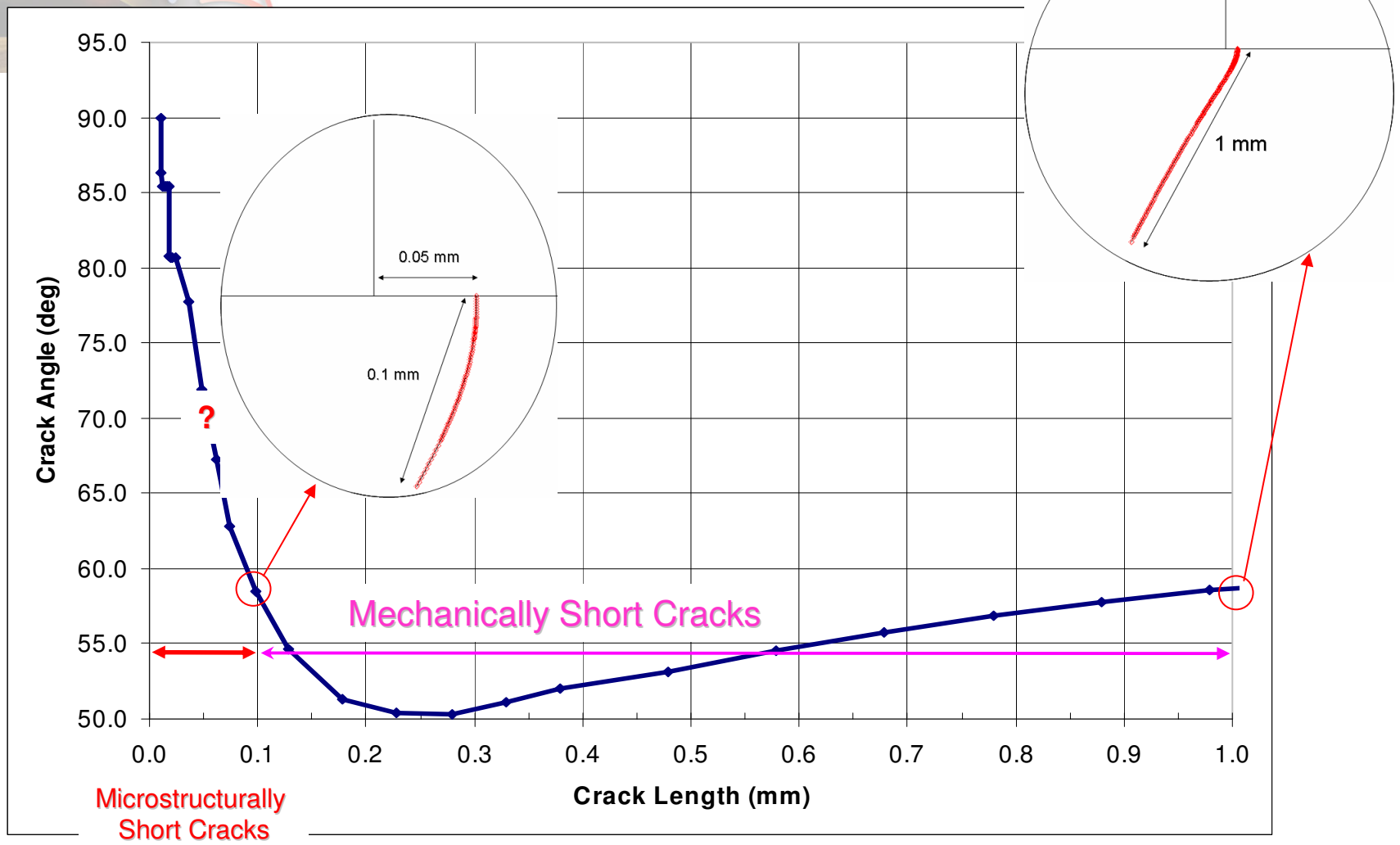




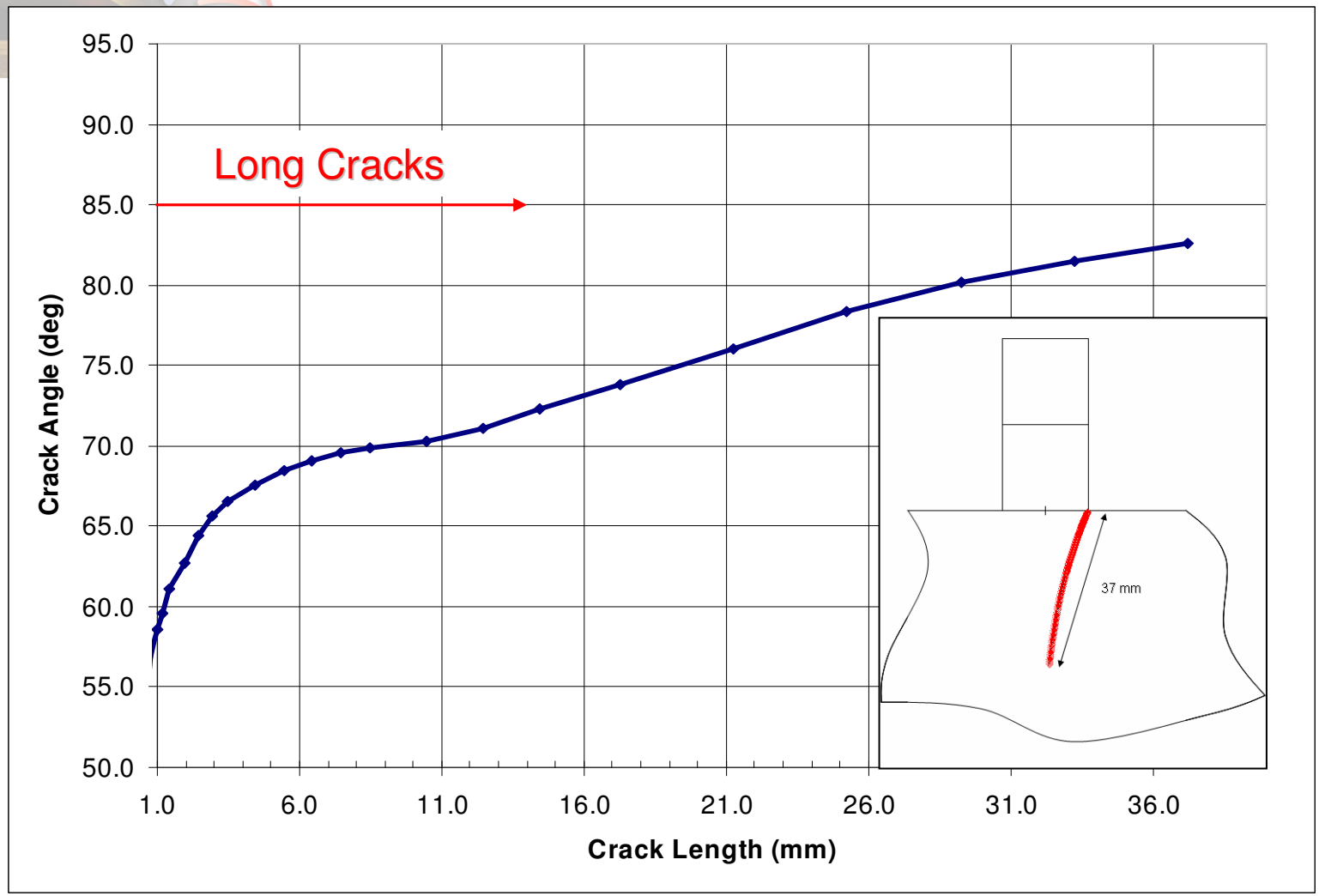
GROWTH DIRECTION OF FRETTING FATIGUE CRACK



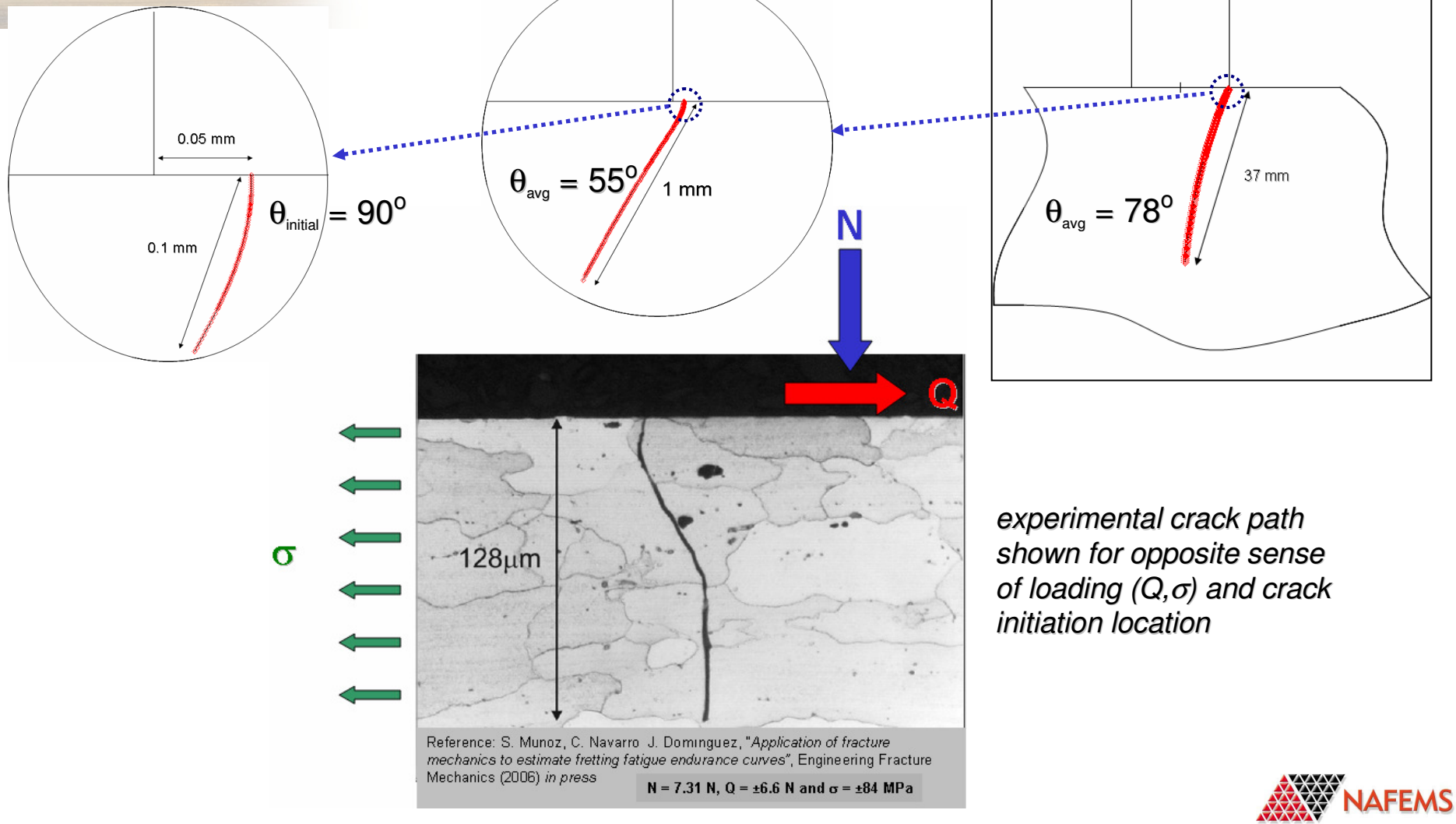
GROWTH DIRECTION OF FRETTING FATIGUE CRACK



GROWTH DIRECTION OF FRETTING FATIGUE CRACK

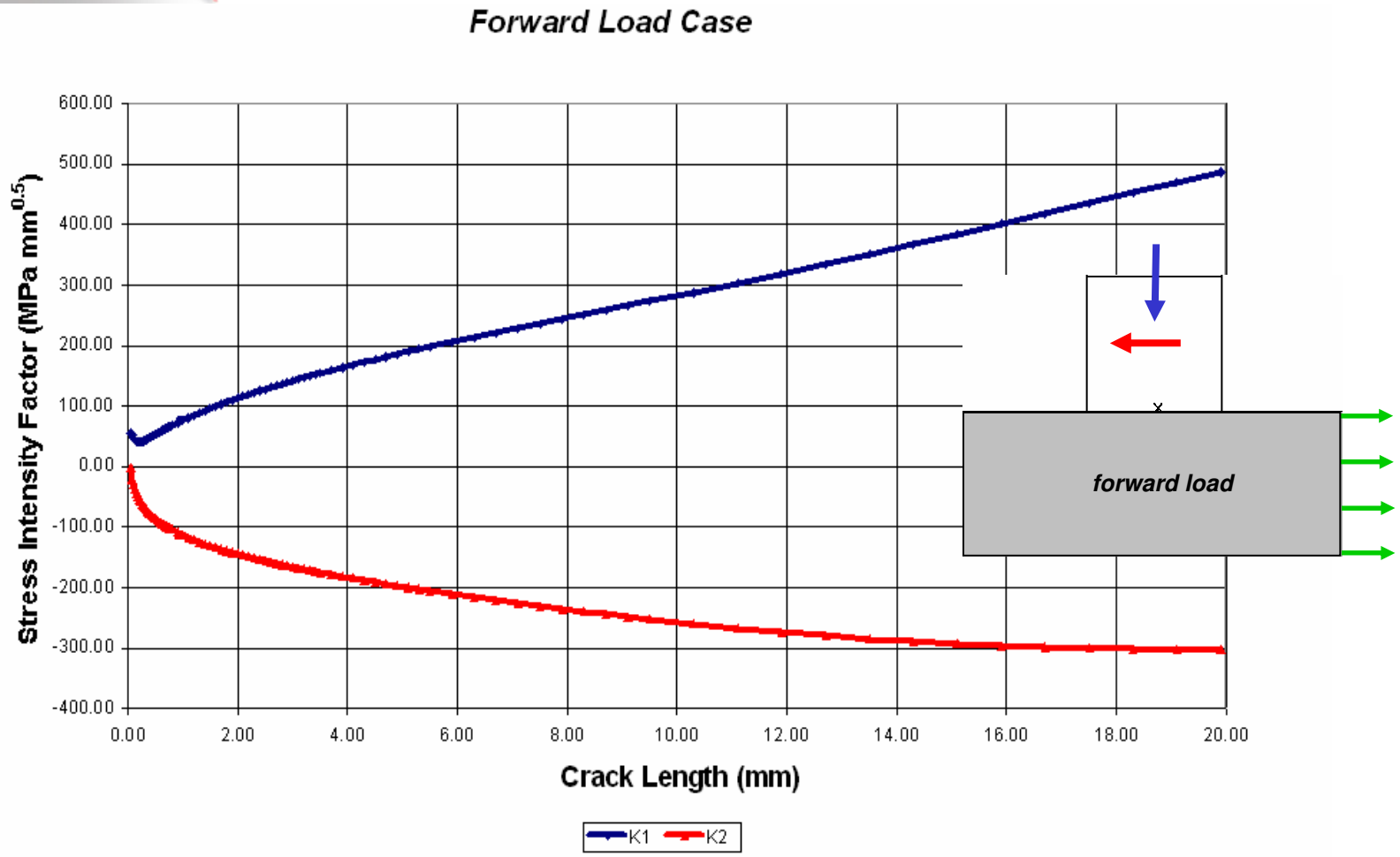


A GENERAL COMPARISON OF CRACK PATH TO TEST DATA

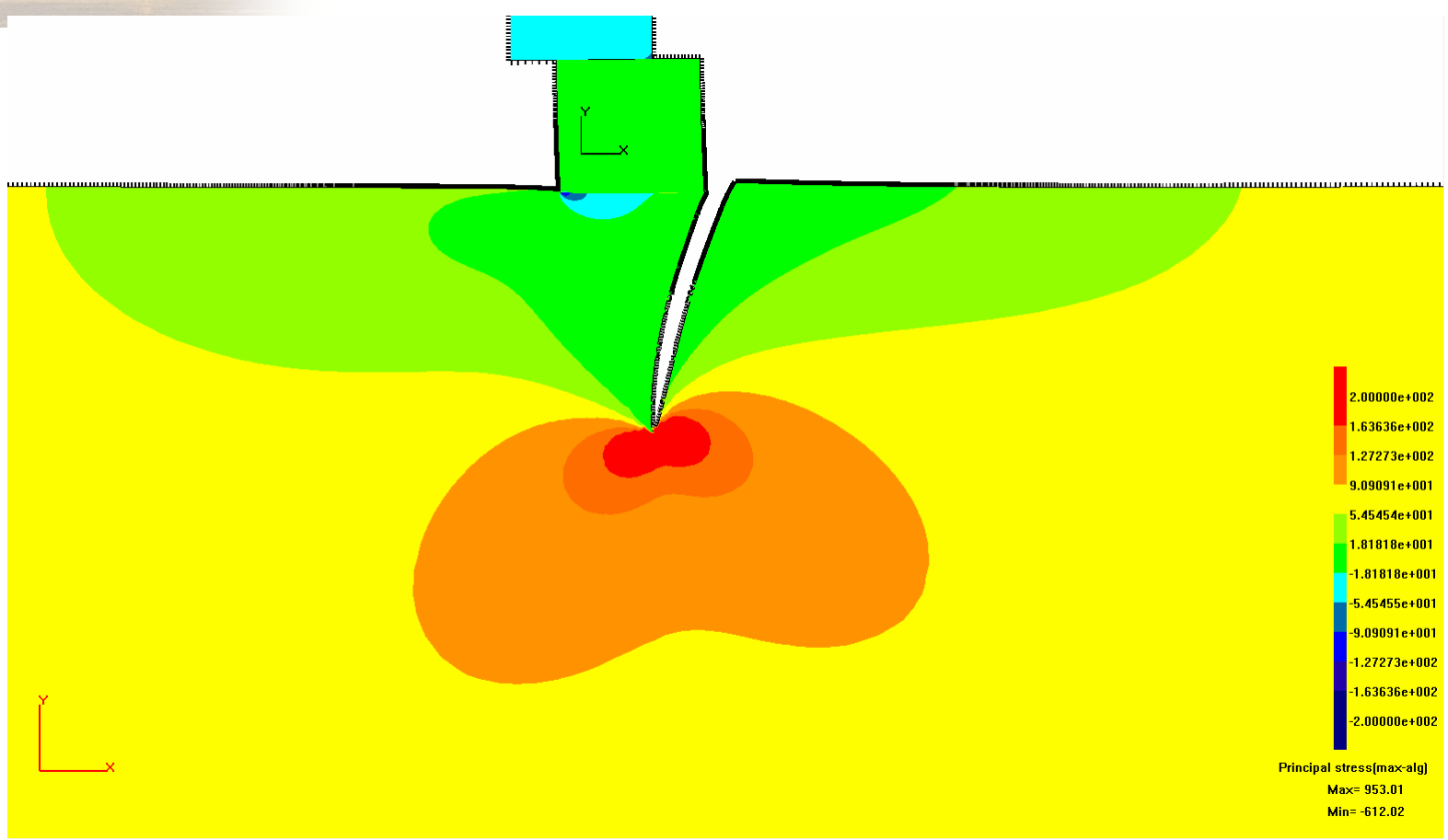


experimental crack path shown for opposite sense of loading (Q,σ) and crack initiation location

MIXED MODE SIF VALUES FOR FRETTING FATIGUE SIMULATION



MAXIMUM PRINCIPAL STRESS NEAR CRACK TIP



IMPACT OF CRACK GROWTH ON EDGE OF CONTACT STRESS

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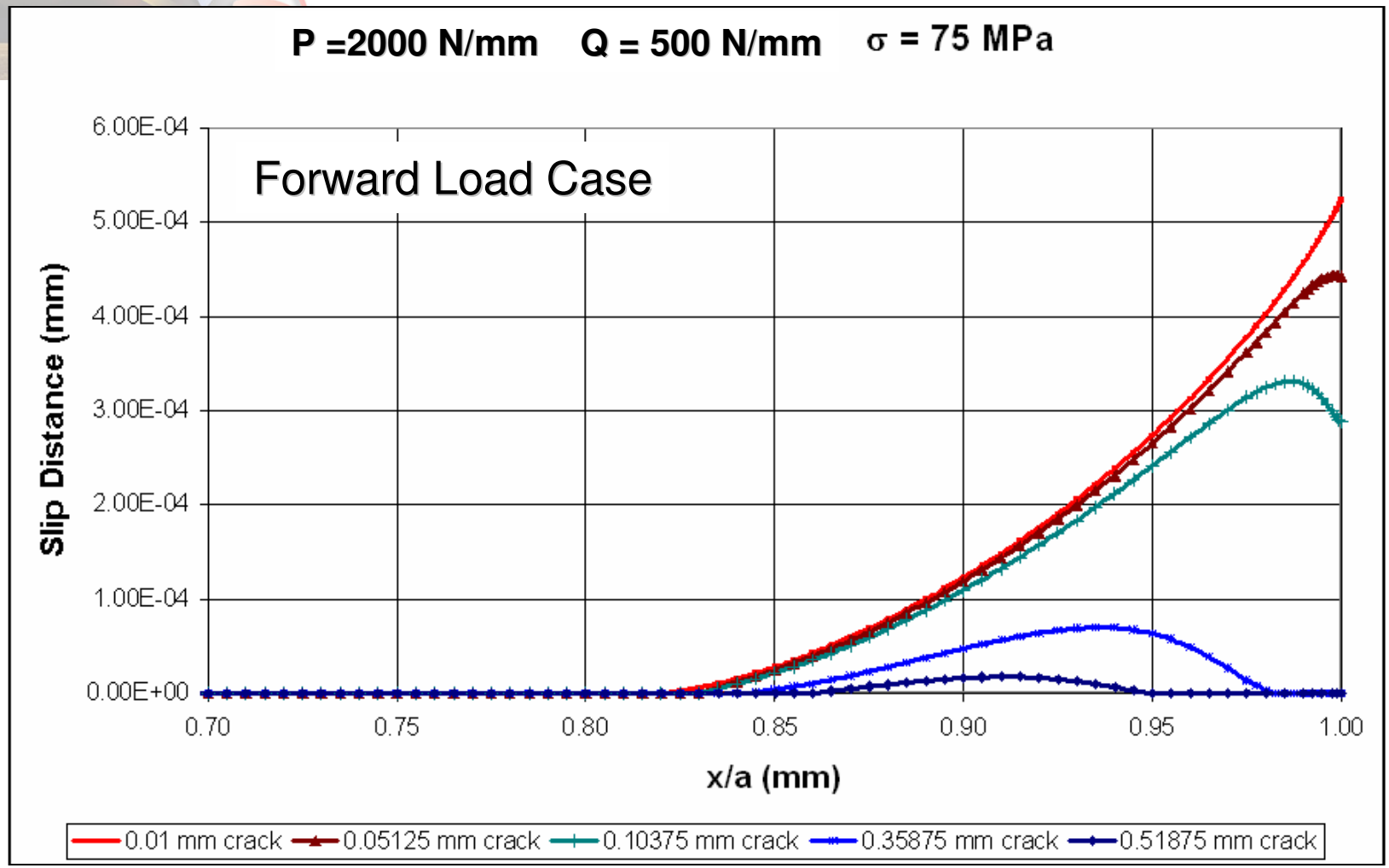
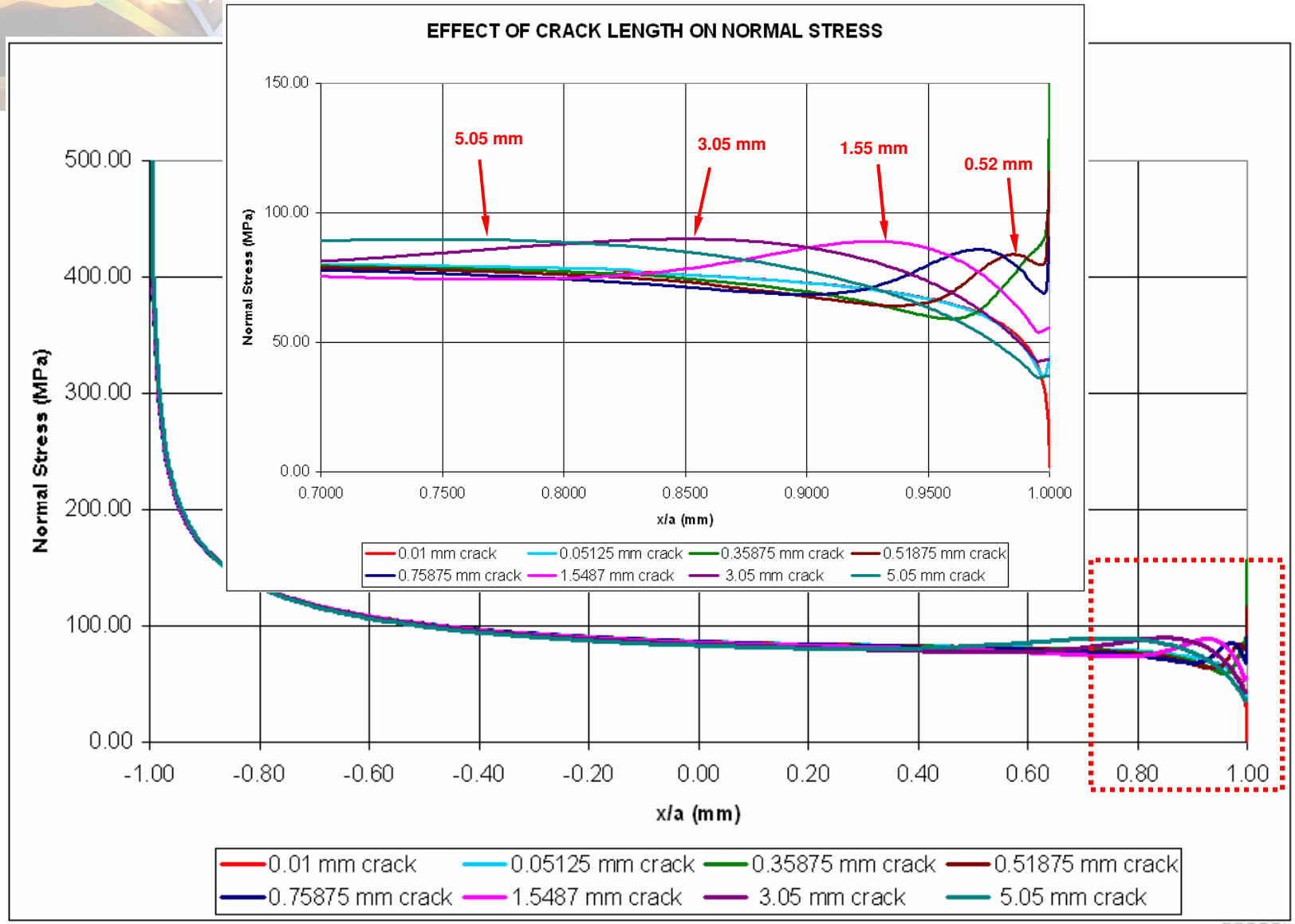
EFFECT OF CRACK LENGTH ON SLIP DISTANCE

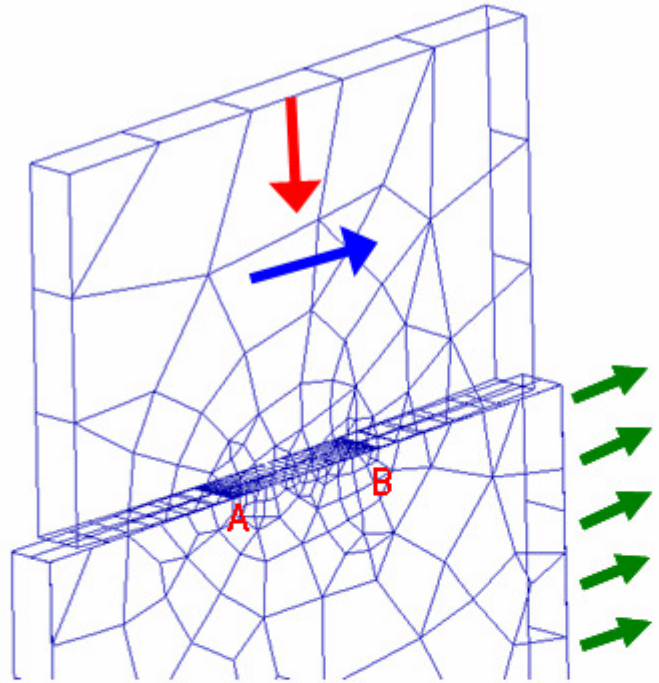


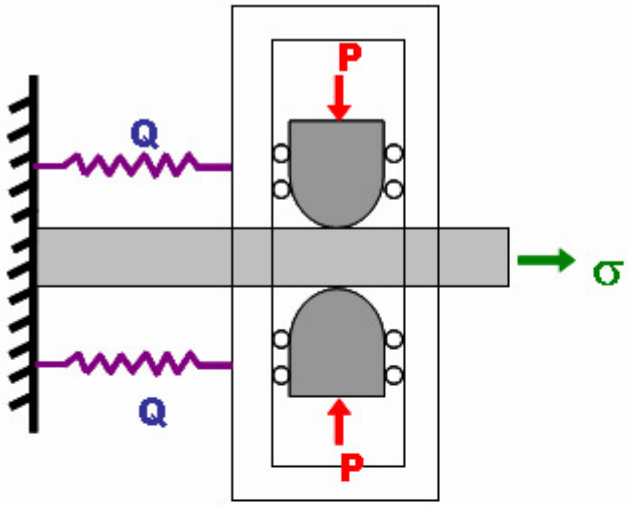
EFFECT OF CRACK LENGTH ON NORMAL STRESS AT EDGE OF CONTACT

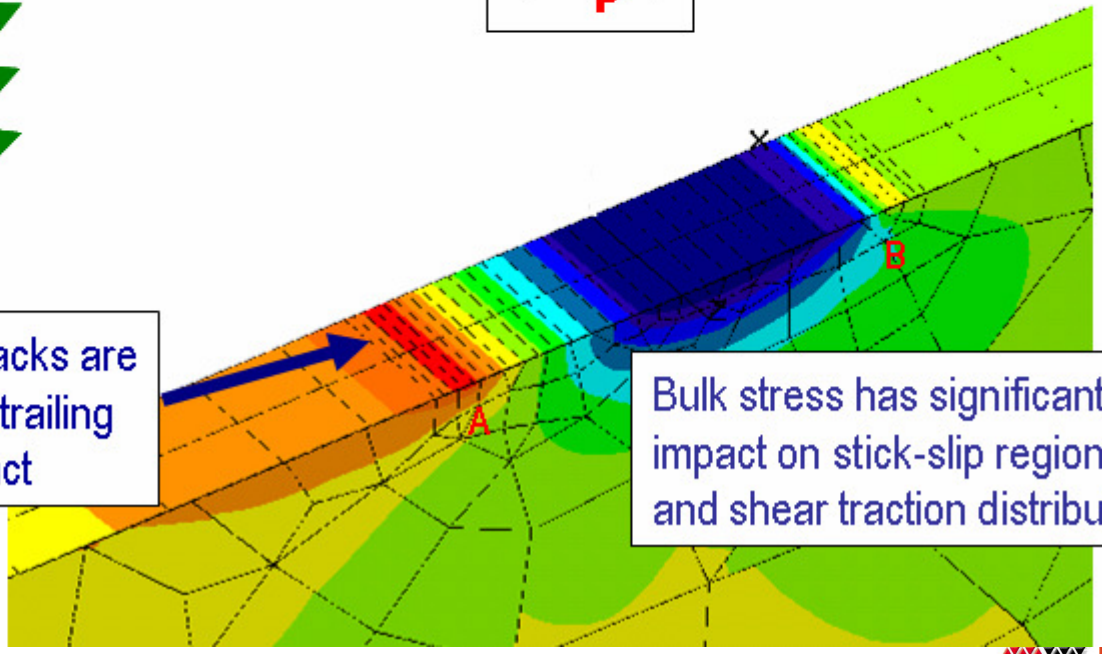


EXTENSION OF METHODOLOGY TO REAL PARTS

Modified Mindlin Contact Solution



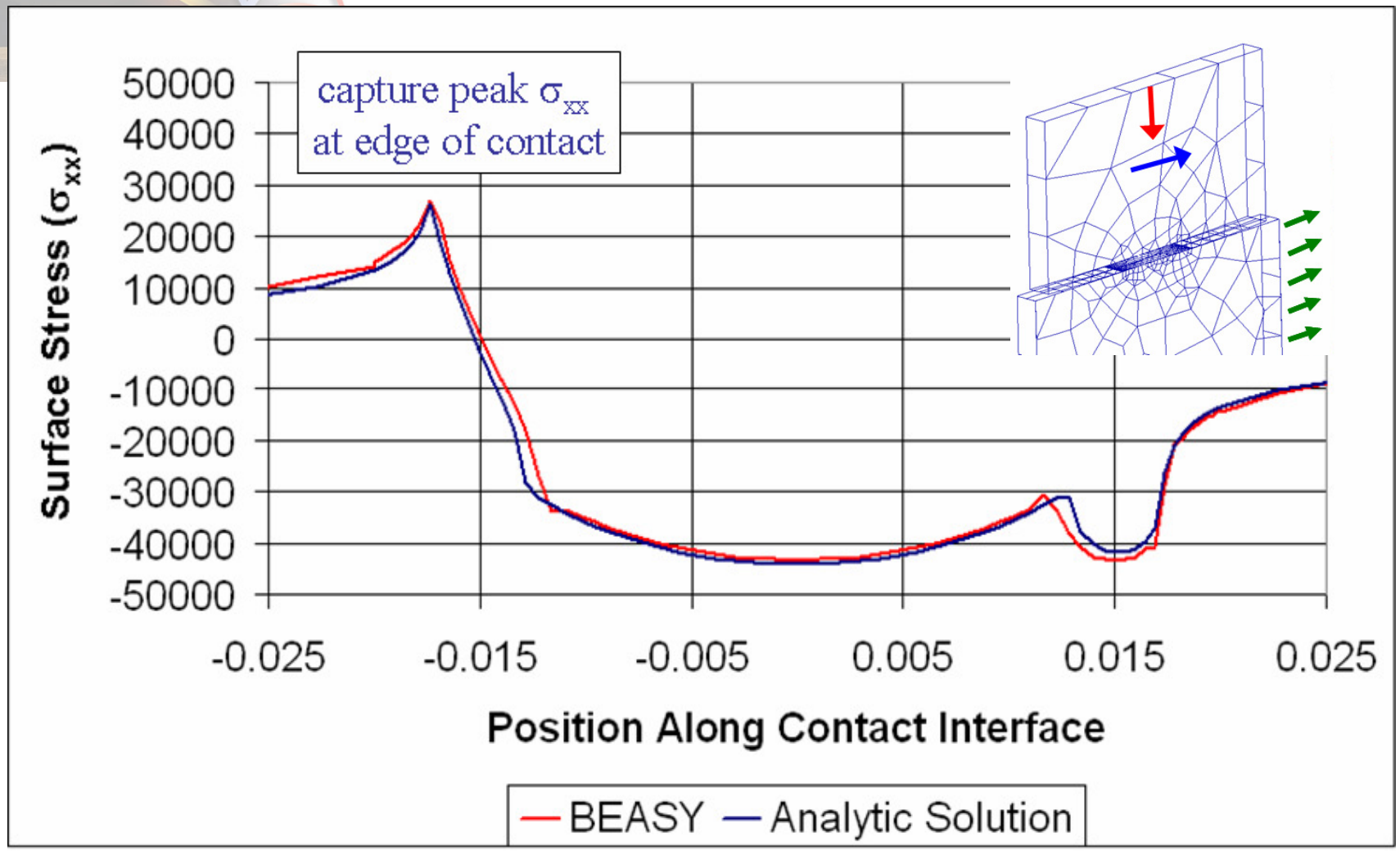




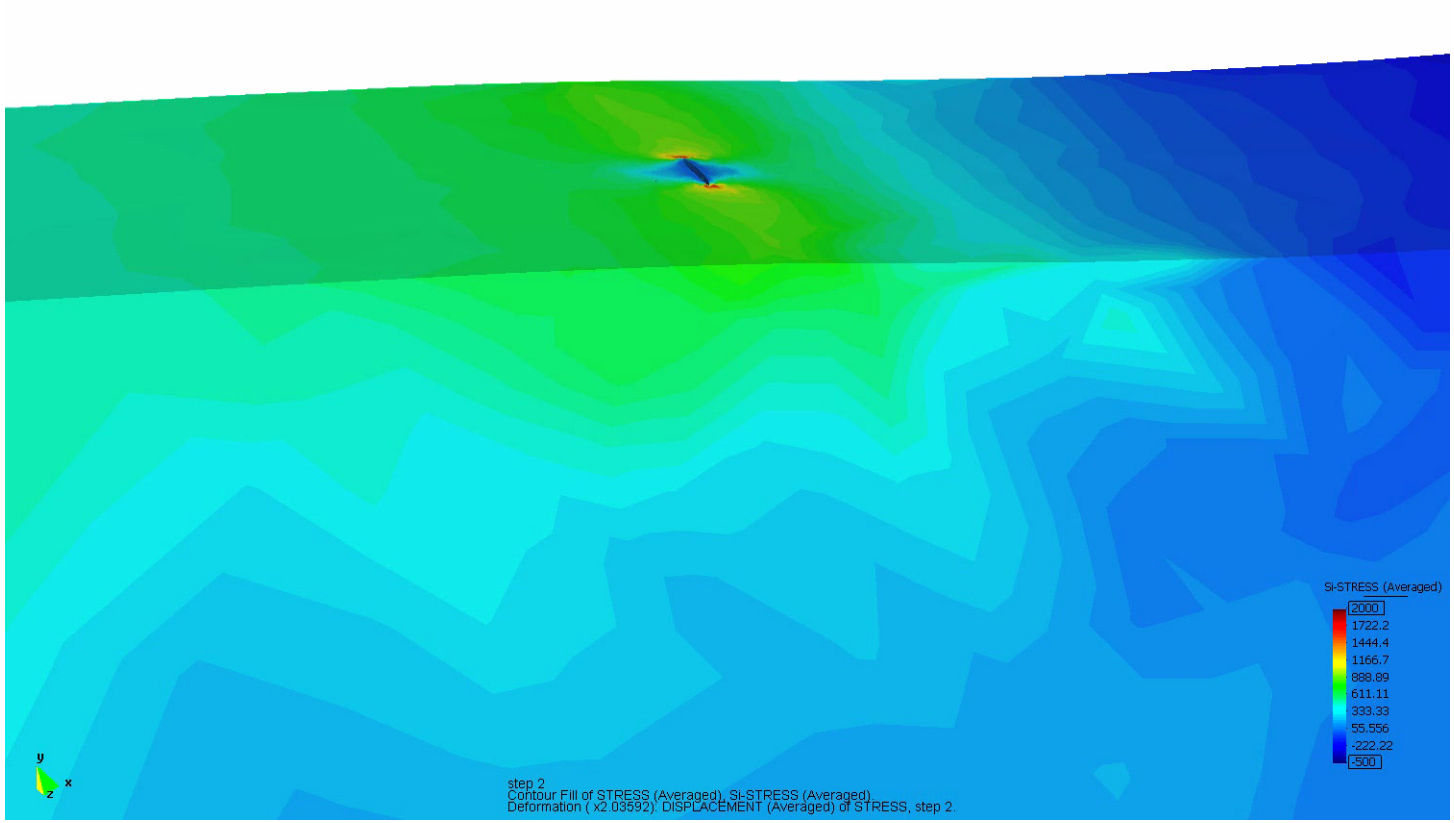
Fretting Fatigue Cracks are often found at the trailing edge of contact

Bulk stress has significant impact on stick-slip region and shear traction distribution

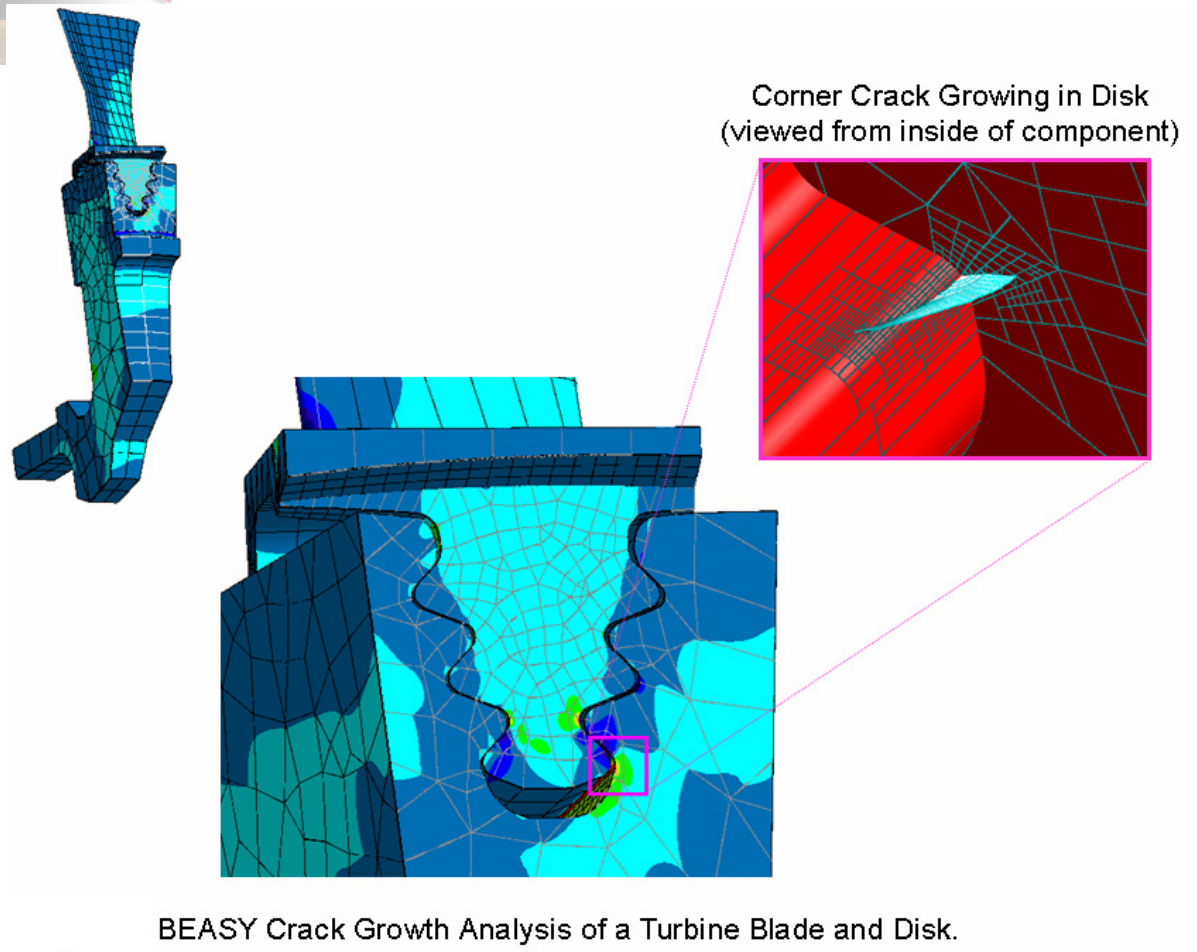
Modified Mindlin Contact Solution



Crack Growth Animation



CRACK GROWTH ANALYSIS OF TURBINE BLADE AND DISK



BEASY Crack Growth Analysis of a Turbine Blade and Disk.

SUMMARY

- Fretting fatigue crack growth is a complex problem involving non-proportional, multiaxial loading and high stress gradients near the edge of contact.
- Boundary element contact solution provides accurate edge of contact stress
- BEASY's crack growth algorithm provides 2D/3D non-planar crack growth and coupled contact/crack growth solutions
- Predicted crack path accounts for continuous change in stress field as the crack is advanced.
- Computer model offers some advantage over analytical solutions in that it accounts for deformation of the contact surface and the inherent geometric nonlinearity that may occur with a shifting stick/slip zone.