FRANC3D Training Workshop: Part 10

SIF History & Fatigue Life

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Workshop Agenda

- Part 1: Introduction to Fatigue and Damage Tolerance
- Part 2: Introduction to Fracture Mechanics Analysis
- Part 3: Introduction to FRANC3D
- Part 4: FRANC3D User Interface
- Part 5: Finite Element (FE) Model Import
- Part 6: Crack Insertion
- Part 7: Static Crack Analysis & SIF Computation
- Part 8: SIFs from FE Analysis
- Part 9: Crack Growth
- Part 10: SIF History & Fatigue Life
- Part 11: Miscellaneous Topics

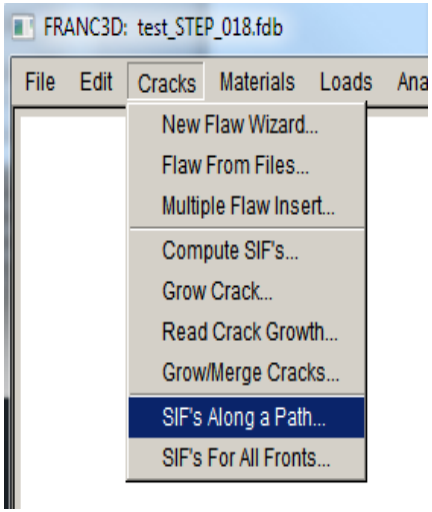
SIF History & Fatigue Life

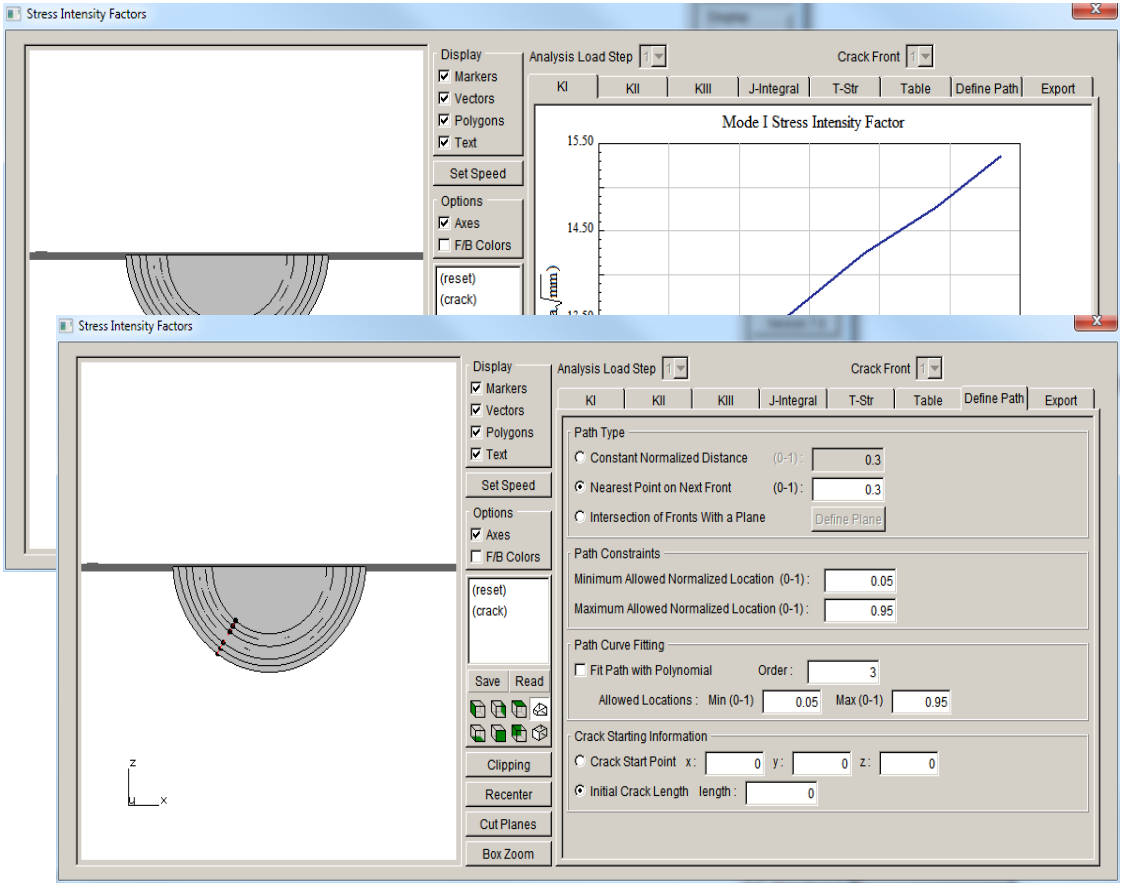
- SIF History
- Computing fatigue life
  - Conventional Single (DOF) Path Approach
  - Multiple Degree of Freedom Approach
- Fatigue Life Predictions User Interface
- Demo: SIF History and Fatigue Life

SIF History

Using a FRANC3D simulation with more than one step of crack growth

- from **Cracks** menu, choose **SIFs Along a Path**

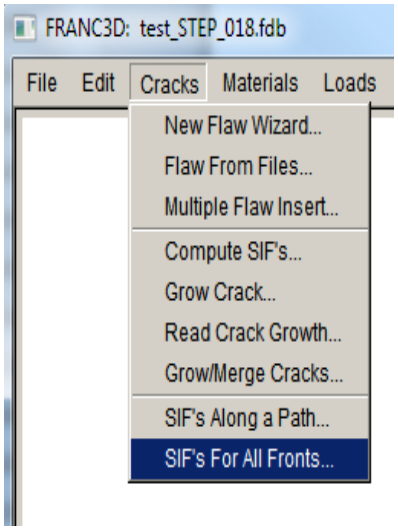




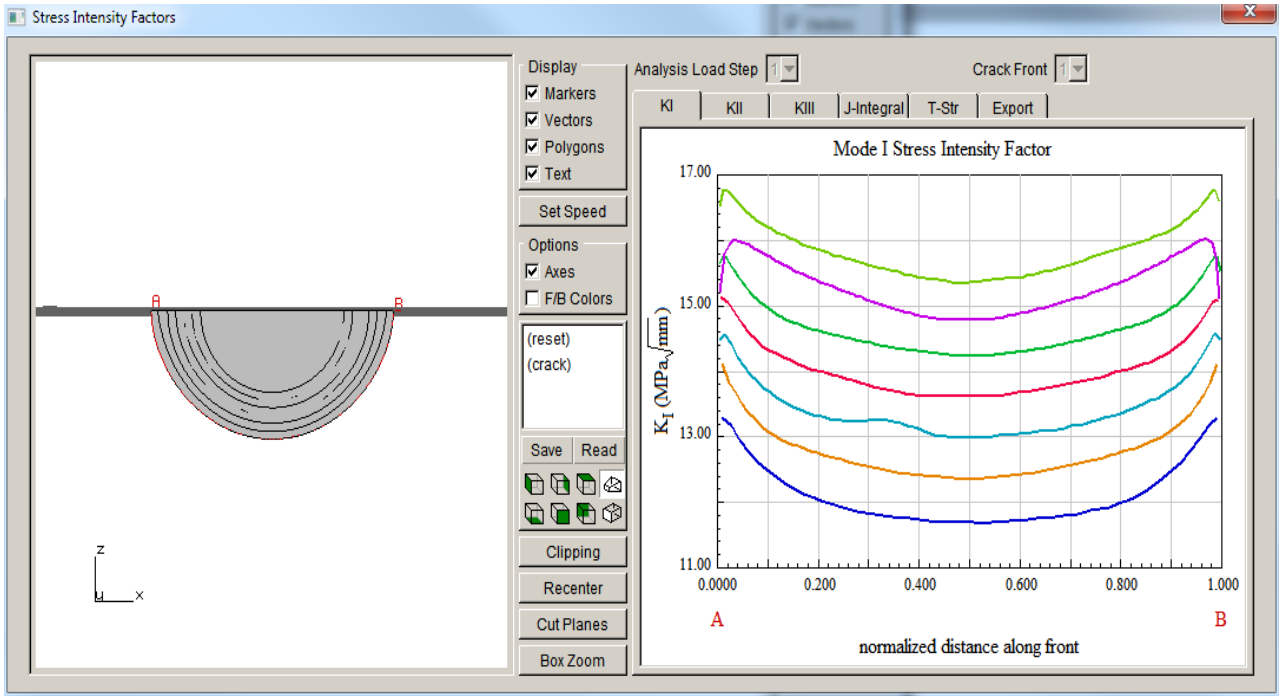
Define different paths to look at SIF variations.

SIF History

– from **Cracks** menu, choose **SIFs For All Fronts**



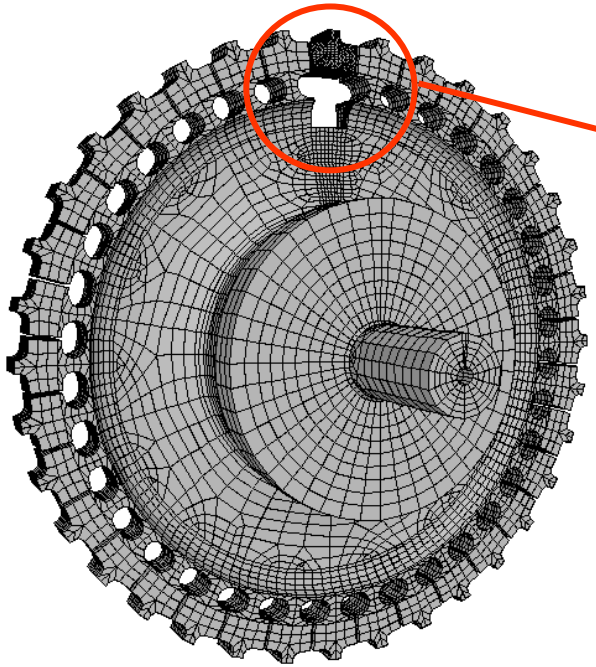
Plot (and export) SIF values along all crack fronts.



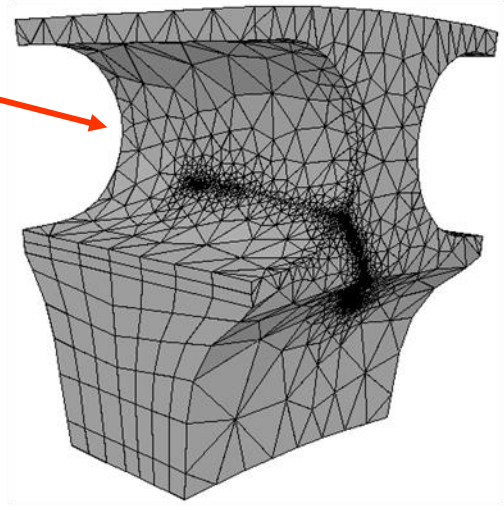
Computing fatigue life

- **Conventional Single (DOF) Path Approach**
- **Multiple Degree of Freedom Approach**

After 22 Steps of Growth

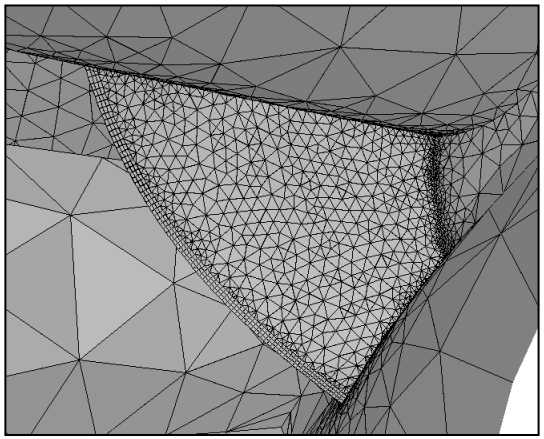


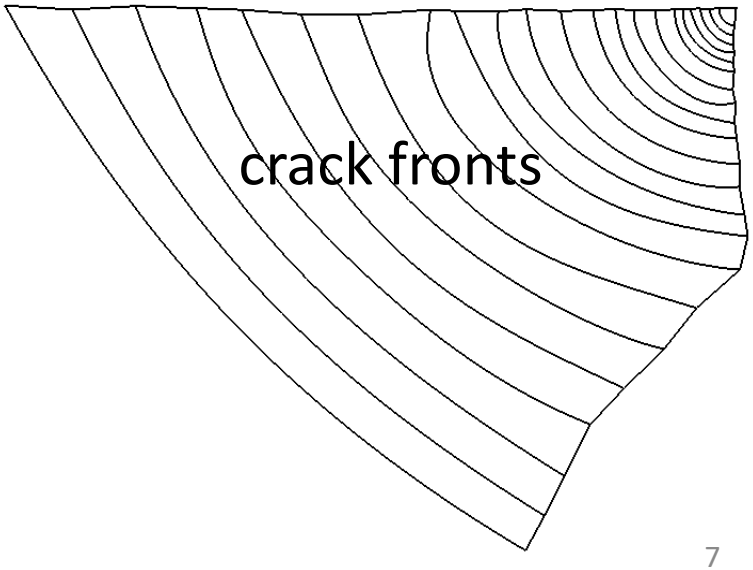
Minidisk



Portion of model contains crack

Crack mesh at step 22

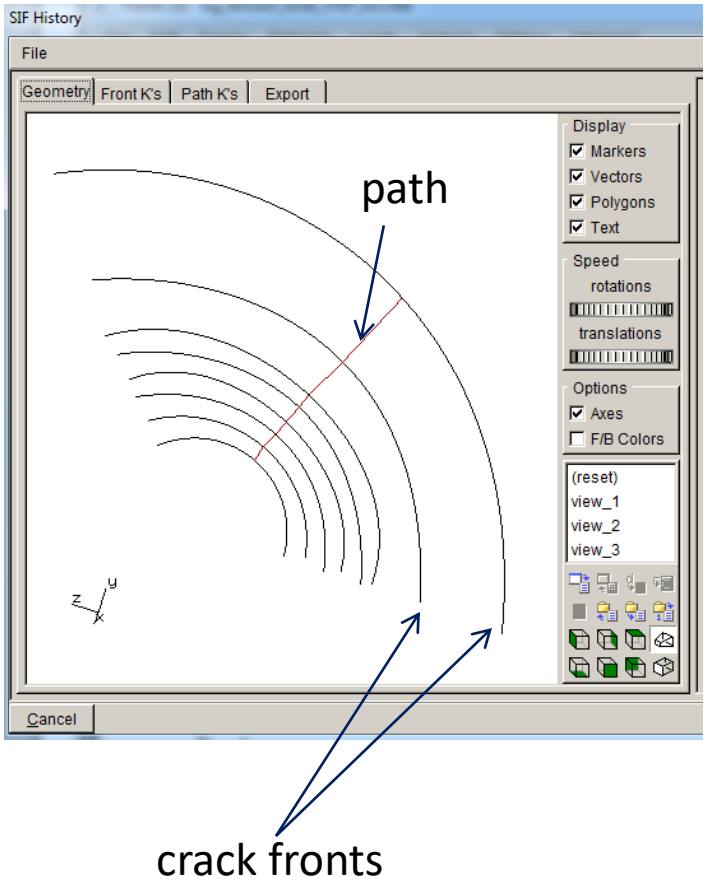




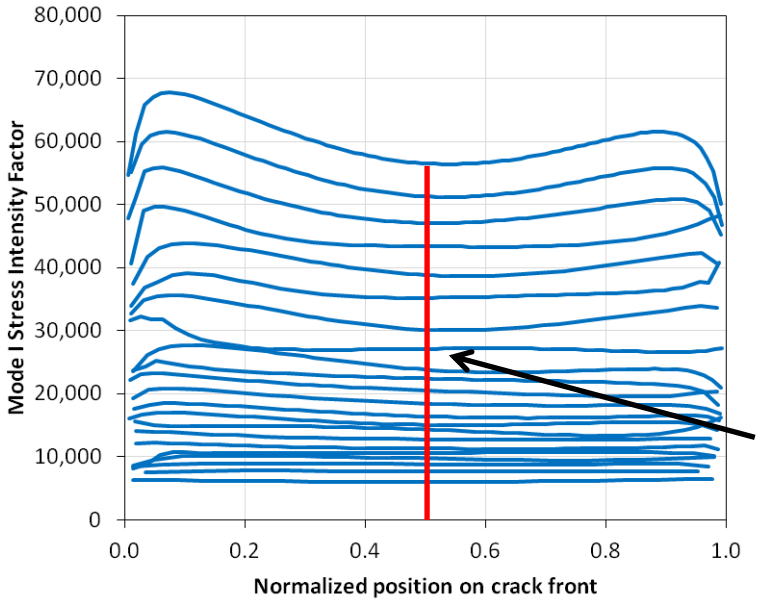
How does one make a fatigue life prediction based on this simulation?

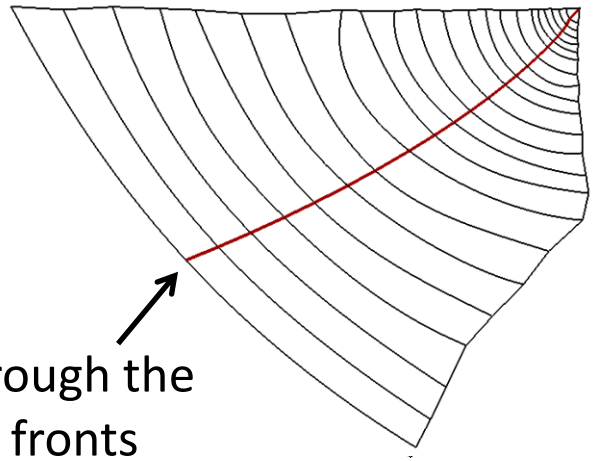
Conventional Single (DOF) Path Approach

- Computing fatigue life (or propagation cycles) involves:
  - Crack insertion and growth
  - Extraction of SIF history for all points on all crack fronts
  - Defining a path
    - through the crack fronts
    - and computing the SIF (K_I, K_{II} & K_{III}) and length along the path
  - Integration using the SIF along the path, the path length, and crack growth rate data or model



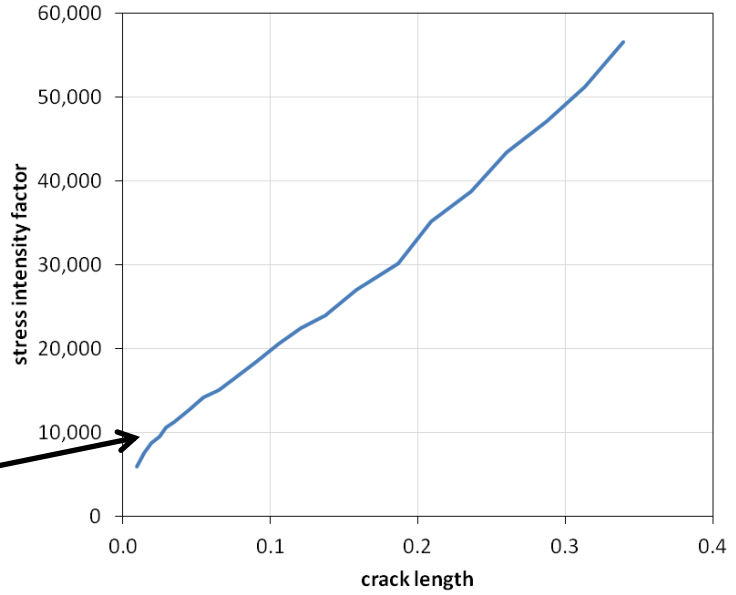
Reducing SIF (K) Data to a Single DOF





Path through the crack fronts

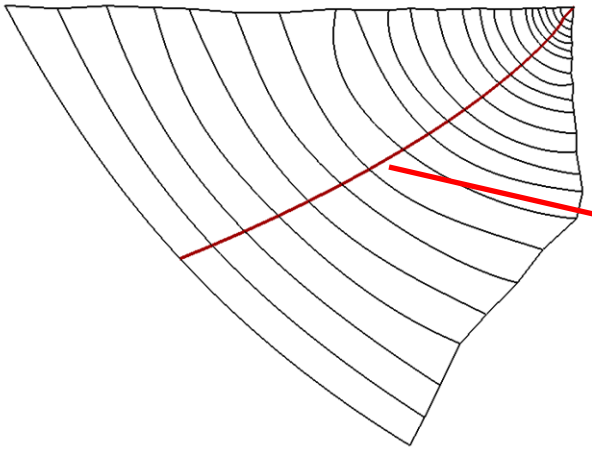
Crack growth simulation yields SIF distributions along each crack front for all crack steps.

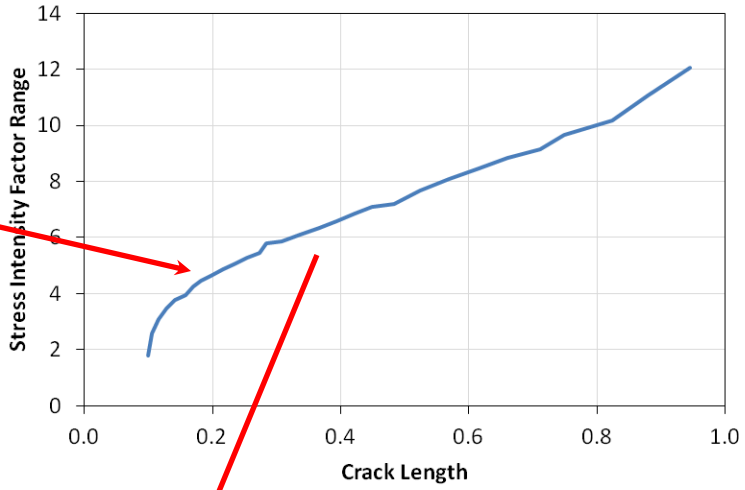


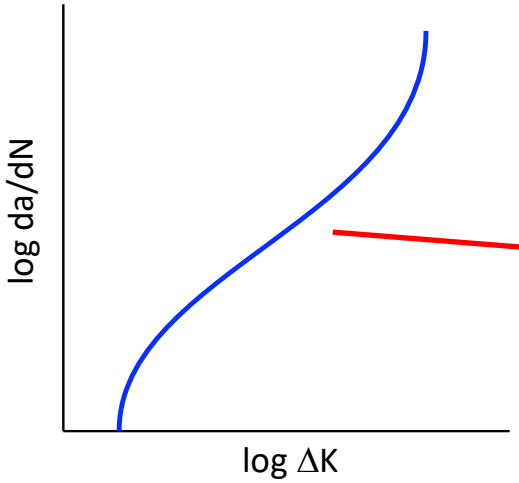
Single degree of freedom (DOF) “K vs a” curve

Conventional Lifing with FRANC3D Results

- A path is defined through the crack fronts that effectively reduces the full 3D results to a single DOF model.



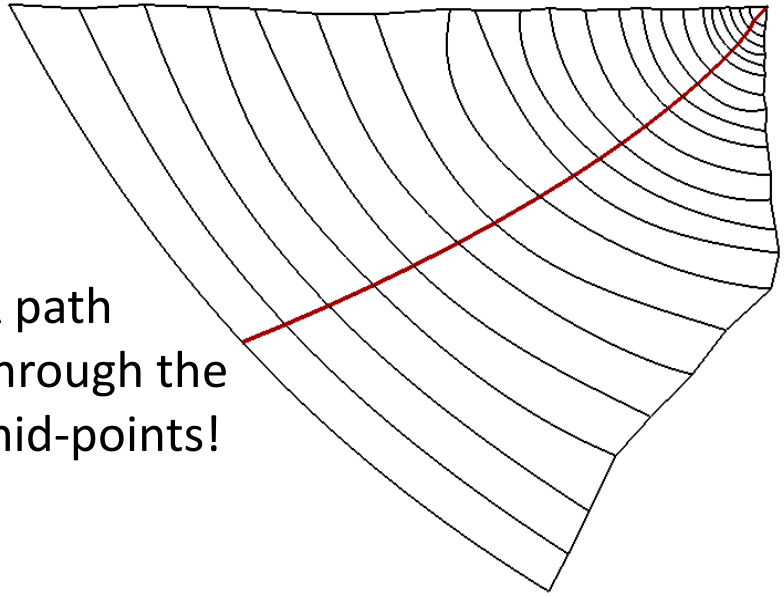


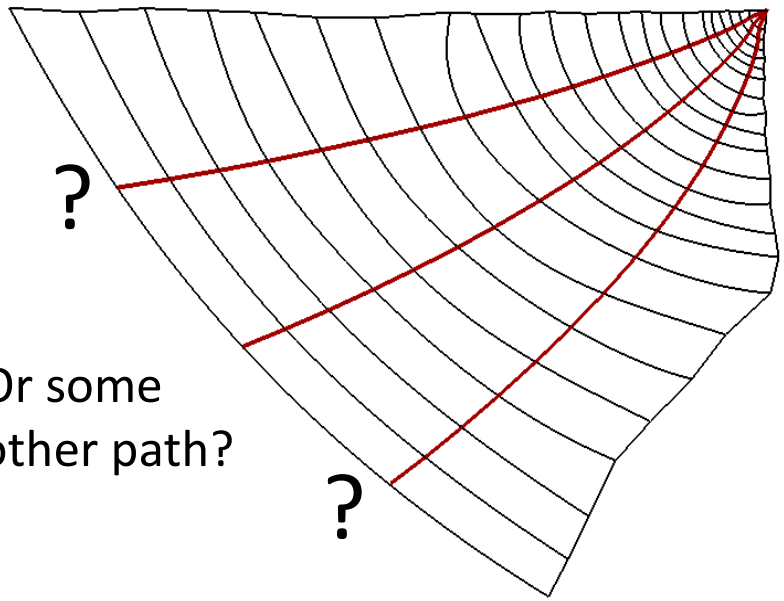


$$N = \int \frac{da}{f(\Delta K, R, \Delta K_{th}, \ldots)}$$

The single DOF SIF (ranges) are integrated with a material crack growth rate model to determine cycles (N).

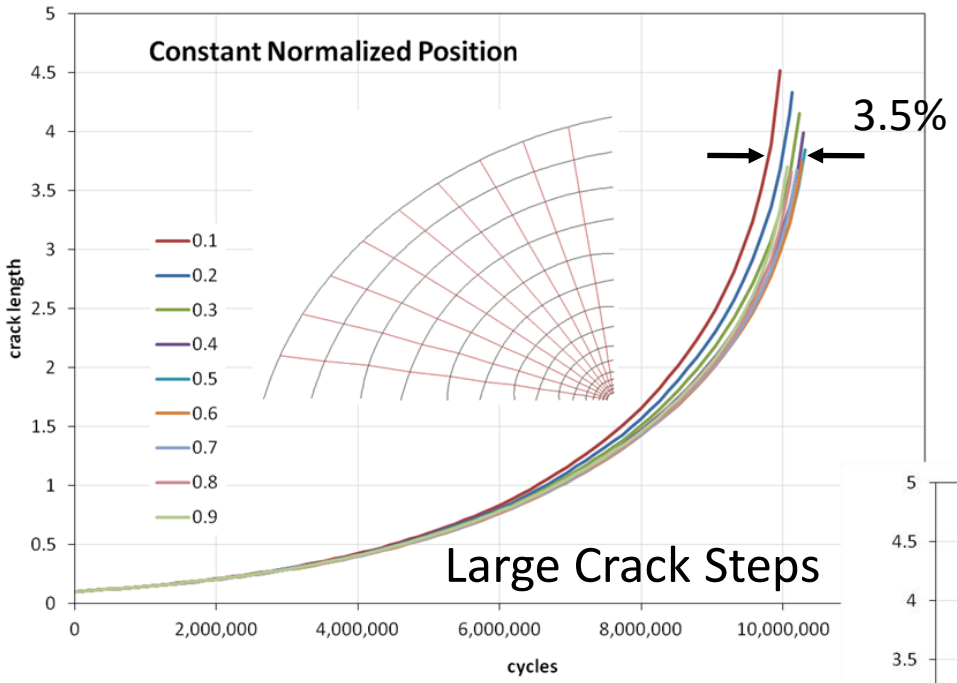
Determining a Single DOF Path(s)



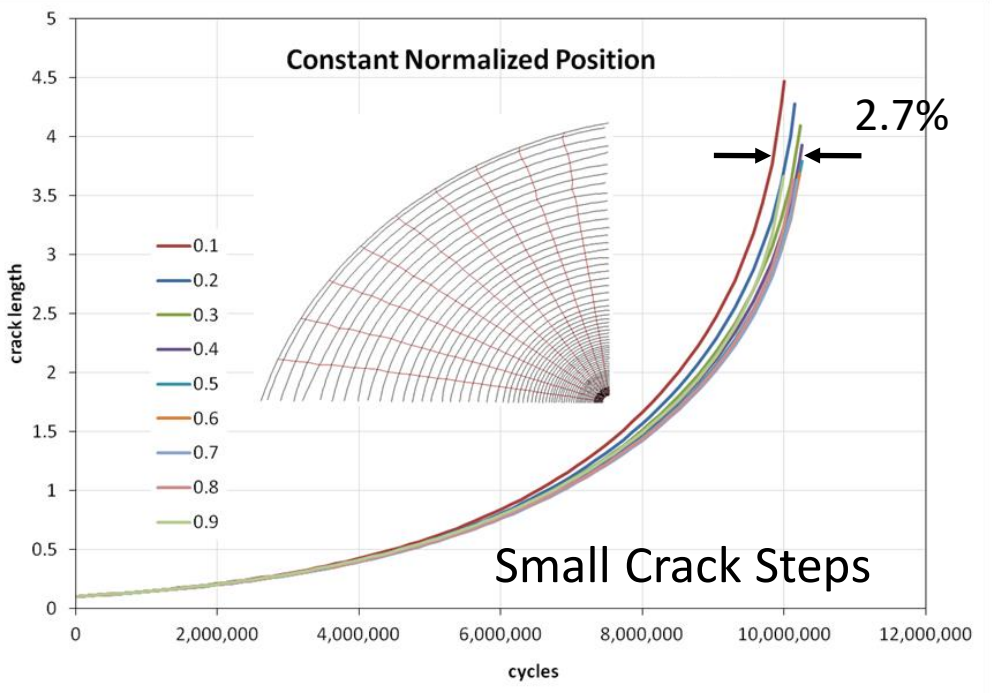


How should one pick the single DOF path, and how does this affect the predicted fatigue life?

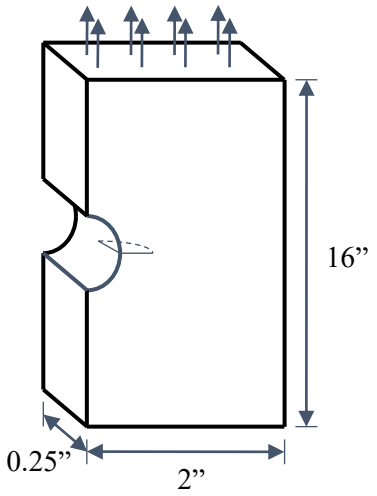
Life Predictions For Different Paths



- Different paths provide different number of cycles; could extract an average or mean and standard deviation.

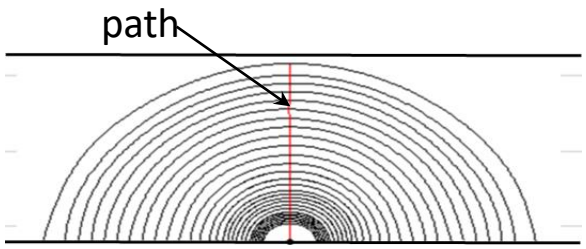


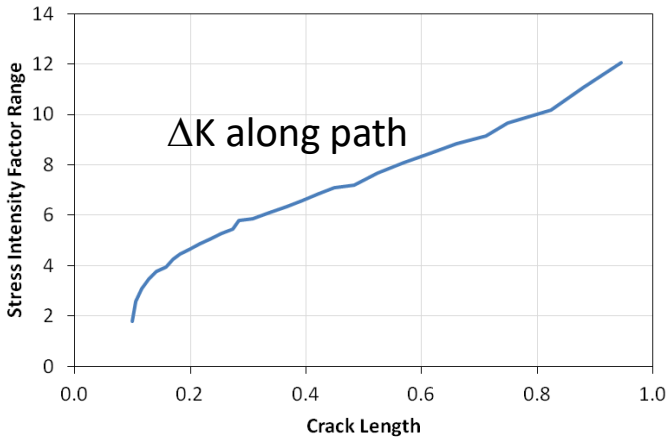
Example: corner crack in a plate under tension



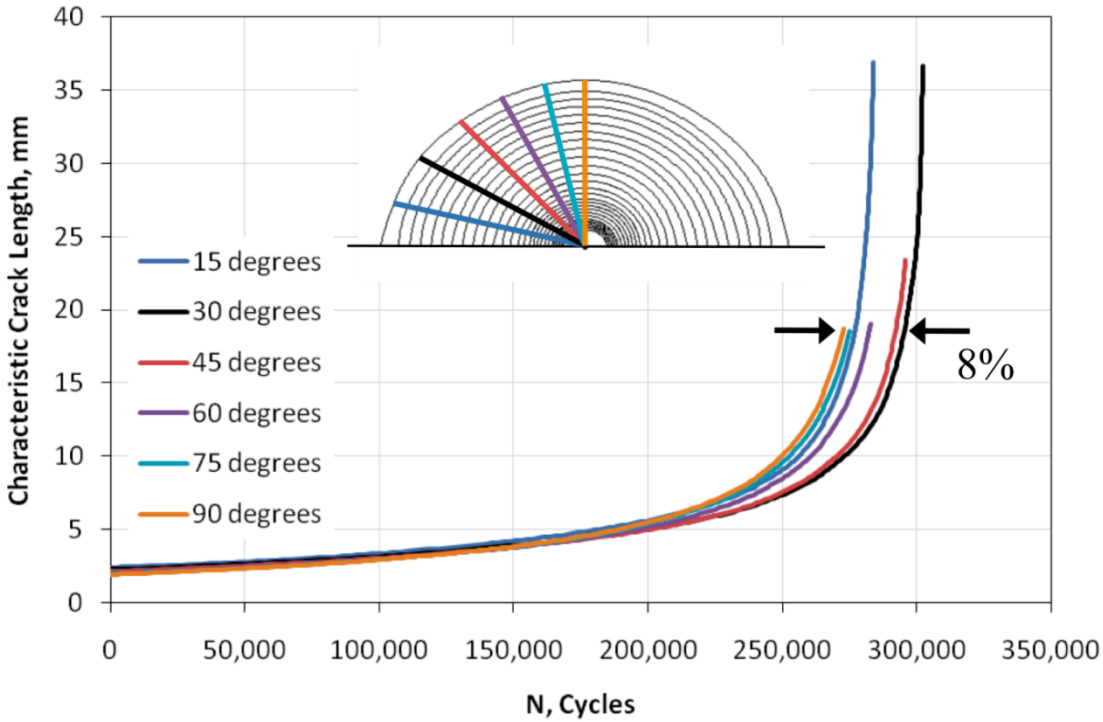
Single DOF Life Predictions

- The least accurate SIFs are computed on the specimen surface; so we choose a path where SIFs are more accurate.



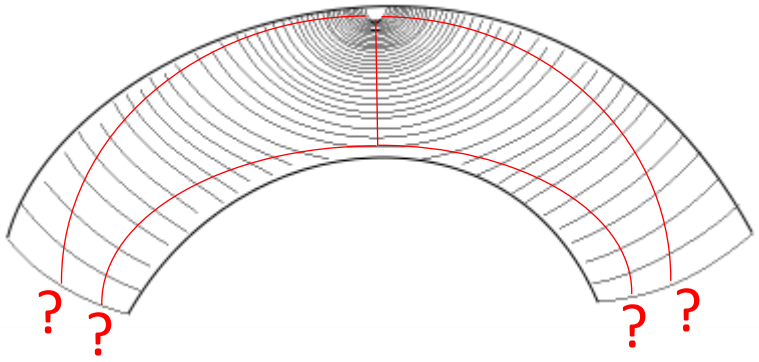


- Comparison of life predictions using SIFs evaluated along six different paths shows a significant variation.



Problems With the Single DOF Approach

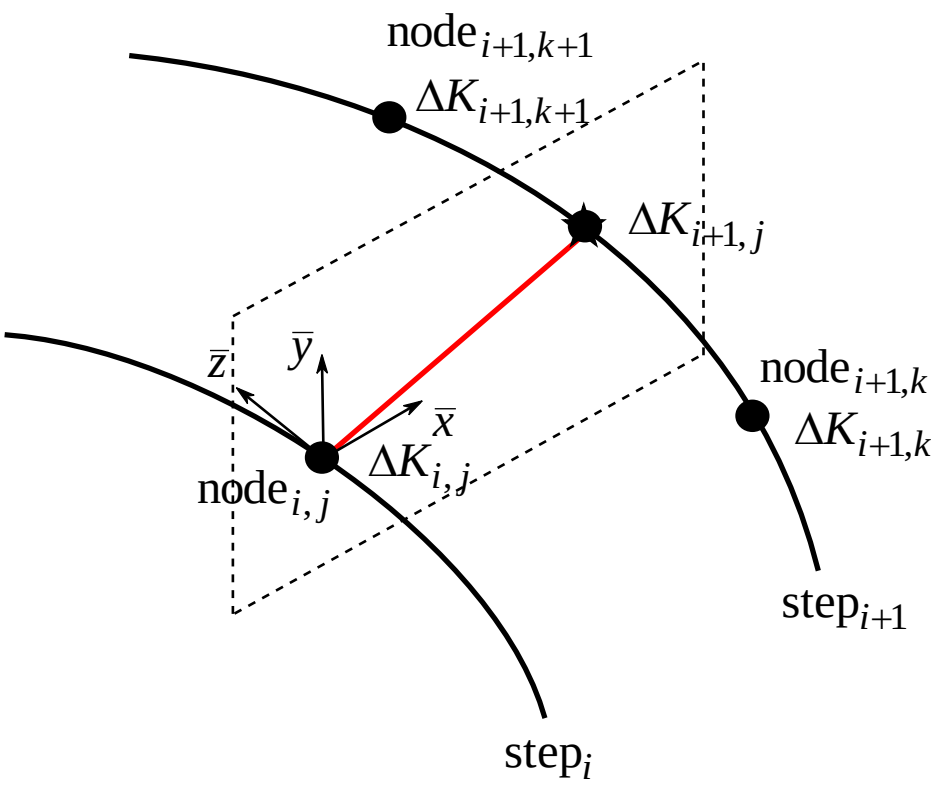
- Defining an appropriate single path becomes difficult for a more complex crack geometry



- Defining a single path requires subjective engineering judgment leading to non-objective life predictions
- Difficult to automate path selection
- Uses only a small amount of the available SIF information
- Can not easily correlate cycles with the observed or measured crack lengths on the specimen surface

For many "real world" models, a single path cannot intersect all crack fronts so multiple paths need to be evaluated.

Multiple/Variable DOF Approach



$$N_{i,j} = \int_0^{\Delta a} \frac{da}{f(\Delta\bar{K}, R, \ldots)}$$

where $$\Delta\bar{K} = \Delta K_{i,j} + \frac{a}{\Delta a}\left(\Delta K_{i+1,j} - \Delta K_{i,j}\right)$$

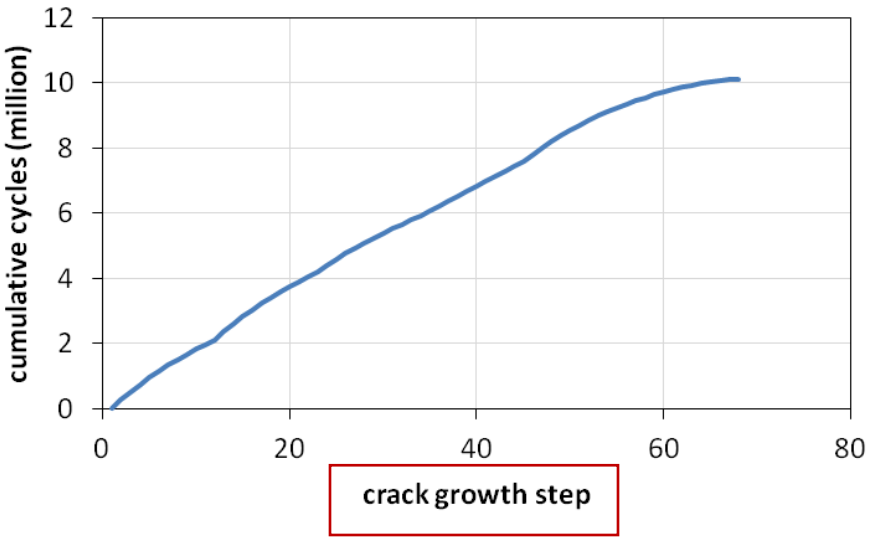
For all nodes on crack front ***i***

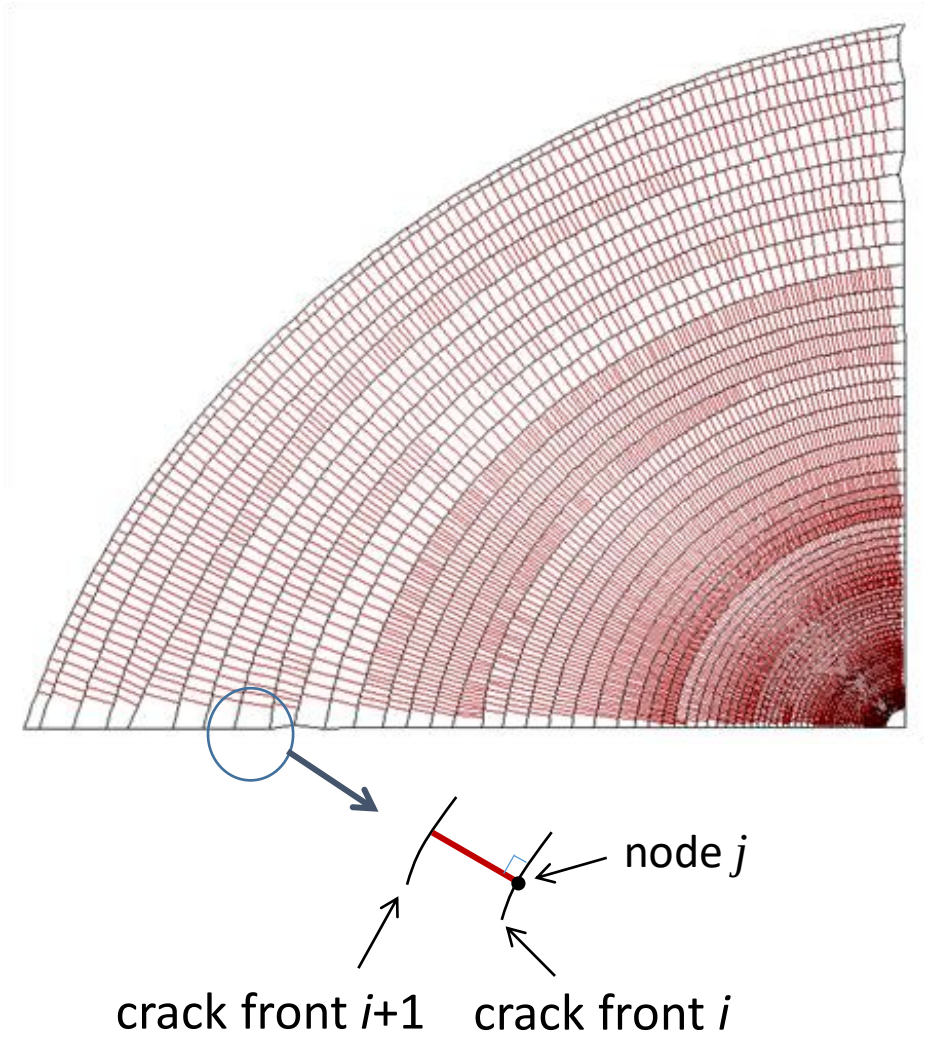
1. Project perpendicular to the crack-front to find the intersection with the next crack front *i*+1
2. Interpolate to find DK at the projected intersection
3. Assume a linear variation in the DK's going from step *i* to step *i*+1 and integrate to find the cycles ($N_{i,j}$)
4. Average the computed cycles for all crack front nodes to obtain one value for cycles required to grow from crack front *i* to crack front *i+1*

$$N_{i \to i+1} = \frac{1}{n}\sum_{j=1}^{n} N_{i,j}$$

Multiple/Variable DOF Approach

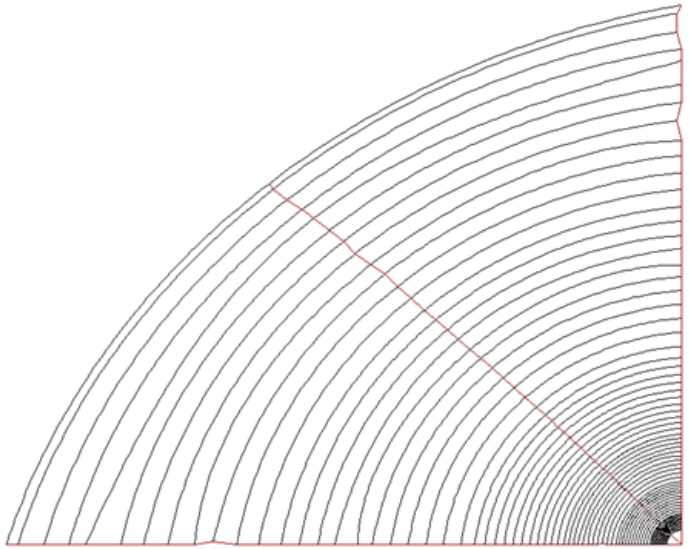
- Compute the number of cycles for all nodes along a crack front
- Compute the average
- Store average cycles versus step of crack growth



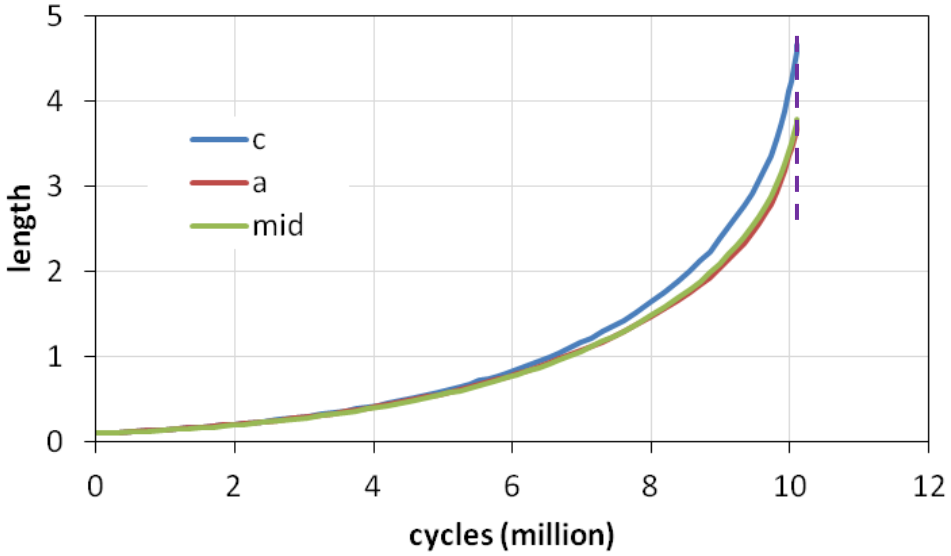


Multiple/Variable DOF Approach

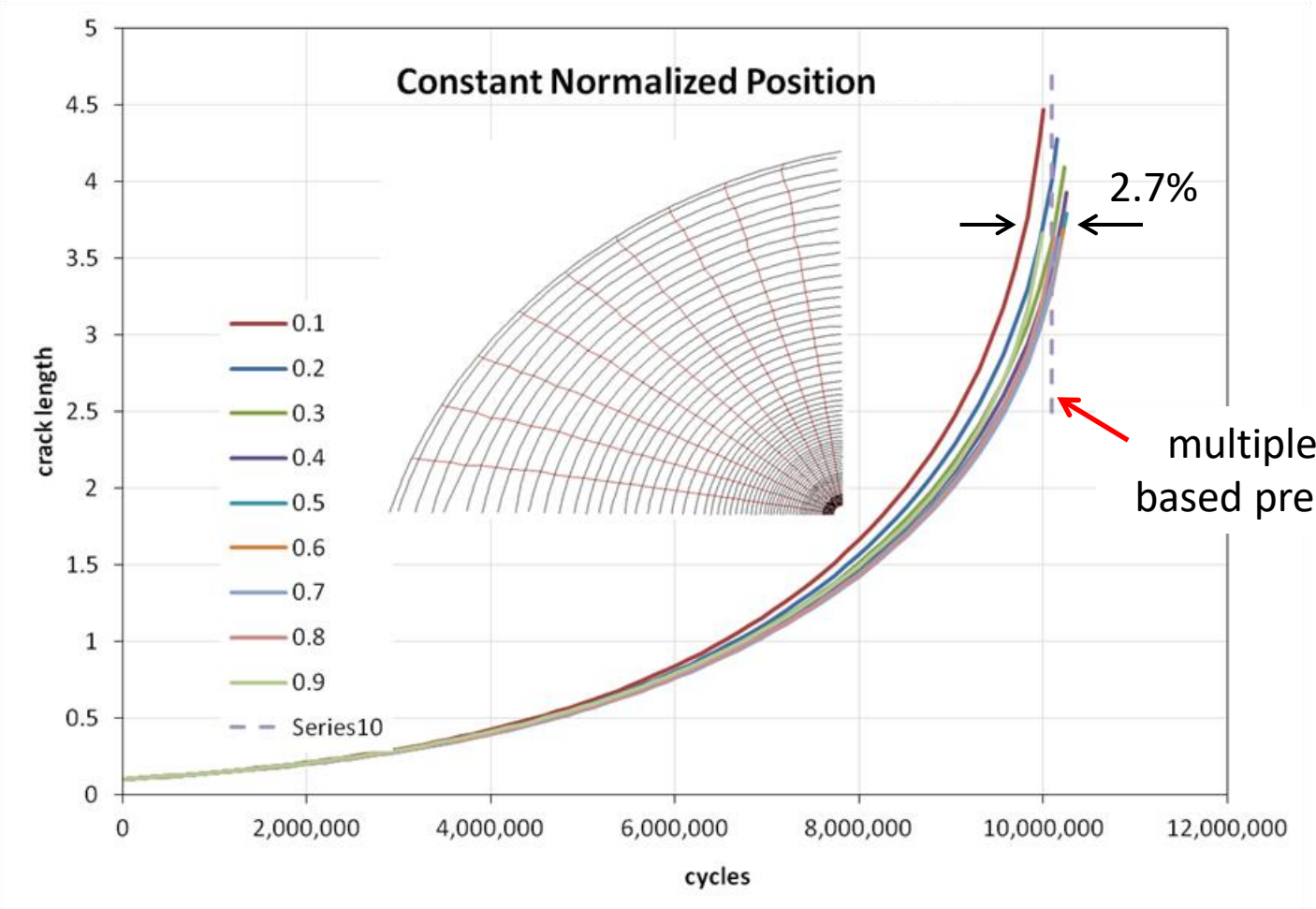
- Life curves can be generated for different paths, and the number of cycles will be consistent.



Can even plot cycles versus crack length for a path on the surface where computed SIFs are not usually accurate.

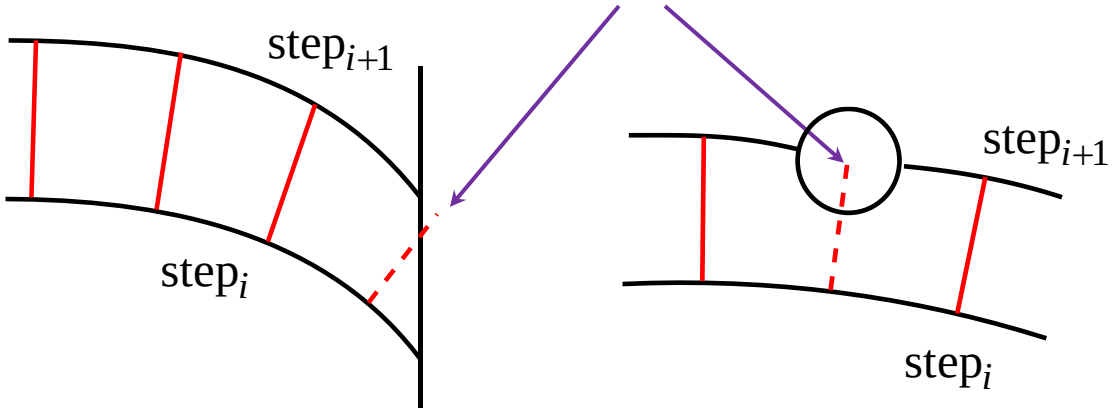


Compare to Single DOF Predictions

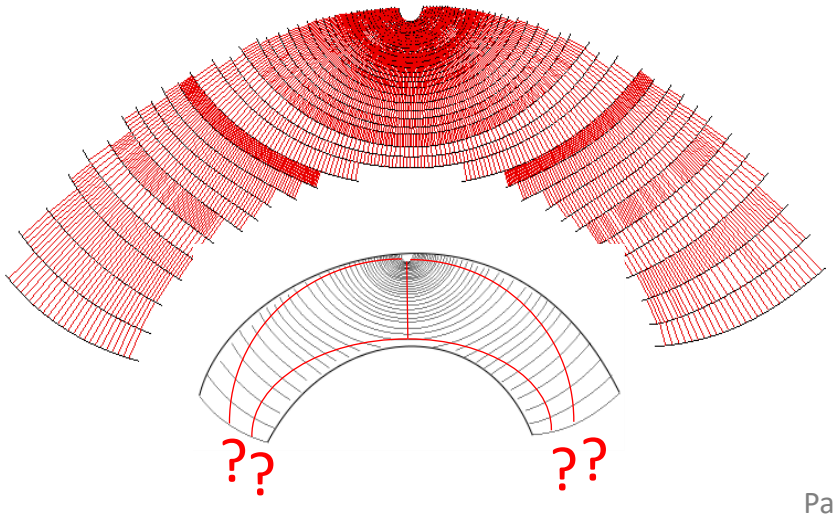


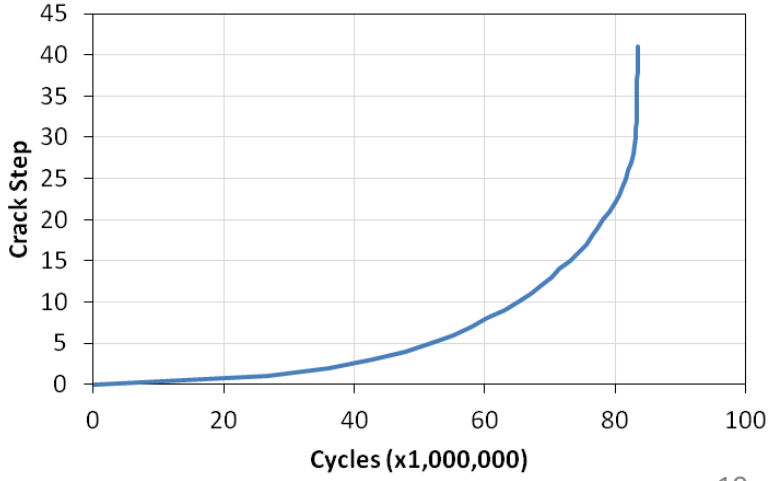
Benefits of Multiple/Variable DOF Approach

- Ignores cases where a projected point cannot be found



- Generates a unique cycle count for each crack front.



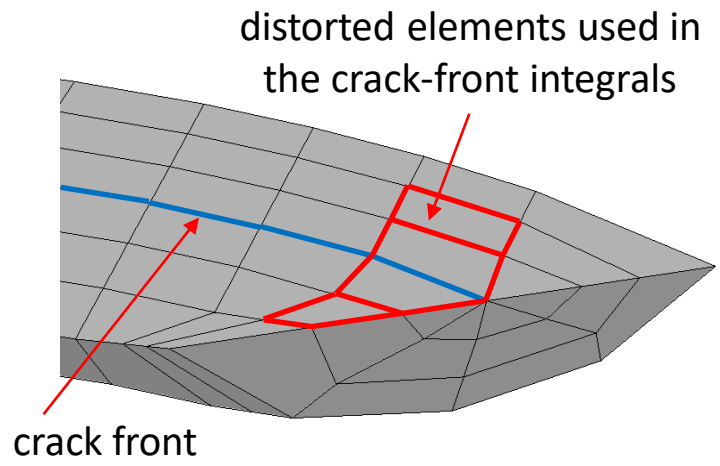


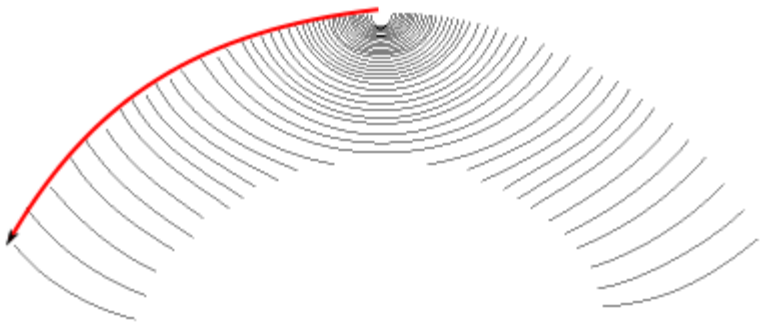
Benefits of Multiple/Variable DOF Approach

- Avoids SIFs computed at surface, which are unreliable because:
  - plane strain conditions do not hold locally, and
  - crack front elements can be highly distorted

- Cycles for each crack step include information from the entire crack front.

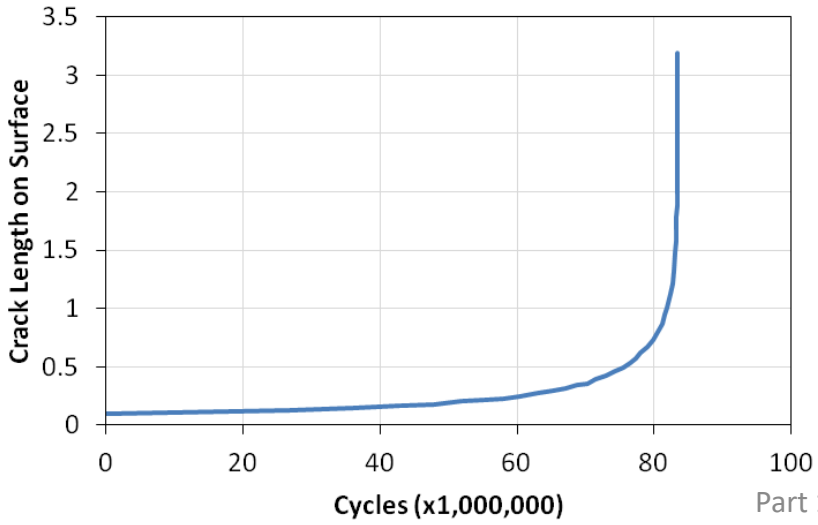
- Generate accurate predictions of cycles versus surface breaking crack length even if we cannot compute accurate stress intensity factors at surface breaking points.

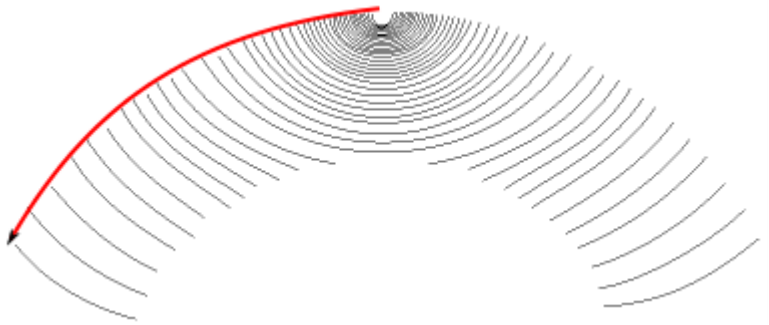




Summary

- Multiple variable DOF approach provides objective life predictions
- Uses all or most of the available SIF data
- Easily automated
- Easily negotiates complex crack shapes
- Generate a versus N curves on surfaces (where computed SIFs are usually inaccurate)

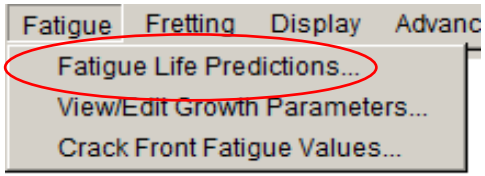


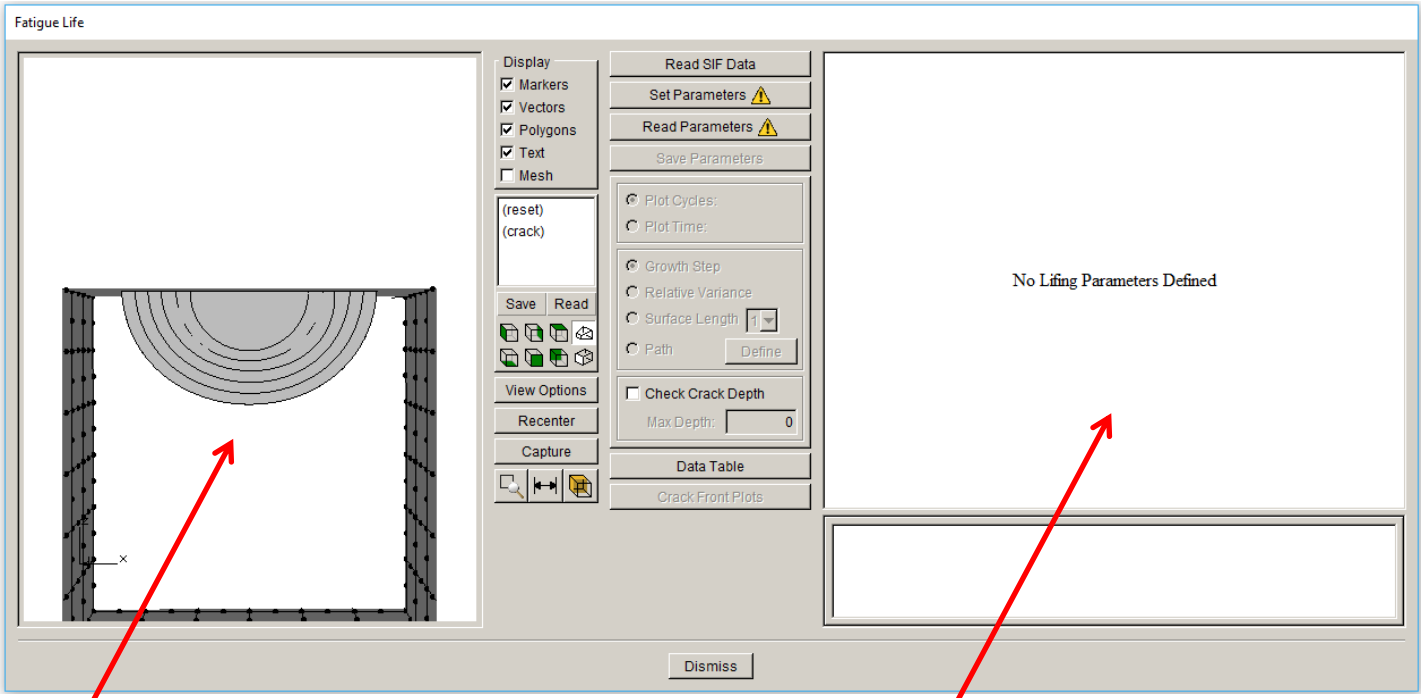


Fatigue Life Predictions User Interface

User Interface

- The Fatigue Life wizard allows the user to compute fatigue cycles





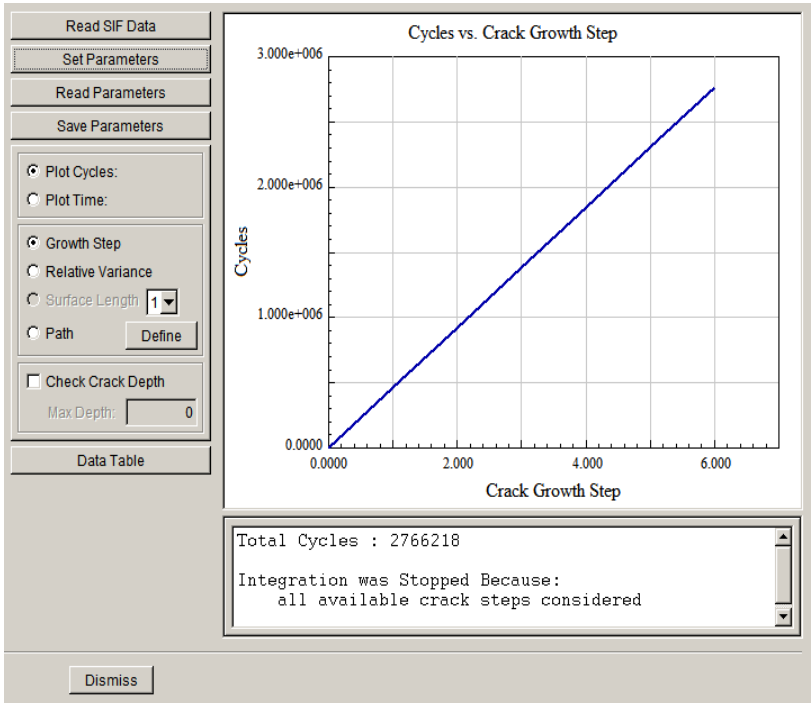
Crack display

Display plots of cycles or time

User Interface

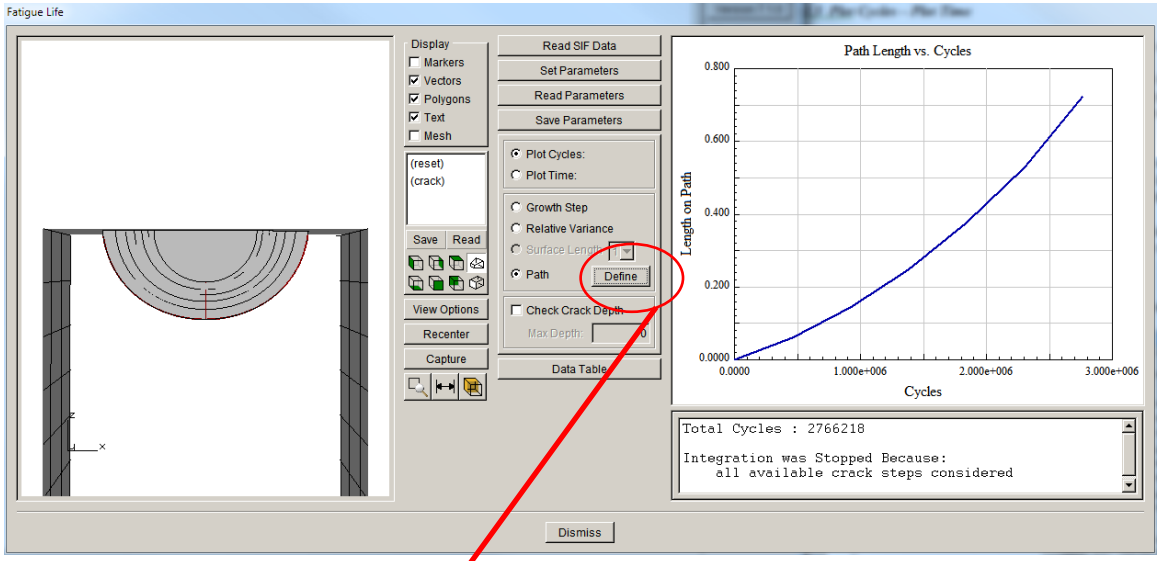
- If crack growth was done using a subcritical growth model, the parameters are already defined and the right-side pane will show a plot of cycles versus crack step

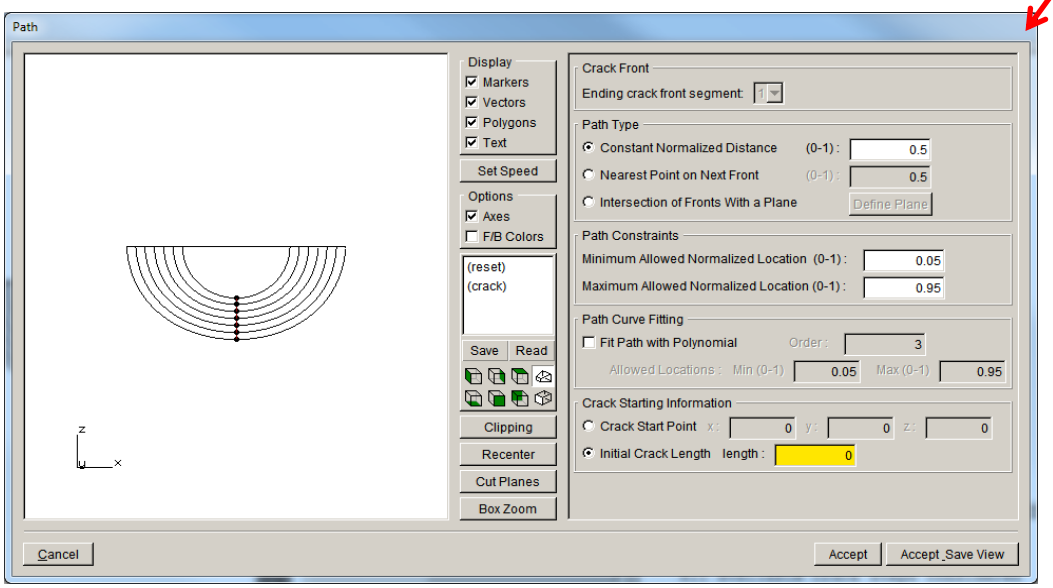
  - **Read SIF Data** button: allows the reading of crack fatigue data (.fcg file) that includes SIF history
  - **Set Parameters** button: Leads to the definition of the crack growth rate model
  - **Read Parameters** button: Allows one to read a previously saved crack growth rate model from a file (.cgp file)
  - **Save Parameters** button: Allows one to save the current crack growth model data to a file (.cgp file)
  - **Plotting**: Allow the plotting of either cycles or time
    - Growth Step
    - Relative Variance: displays the standard deviation in the computed data
    - Path: Allows the user to define a Path
  - **Data Table** button: Displays whatever data is currently active, in tabular form; it can be **exported** to a .txt file



User Interface

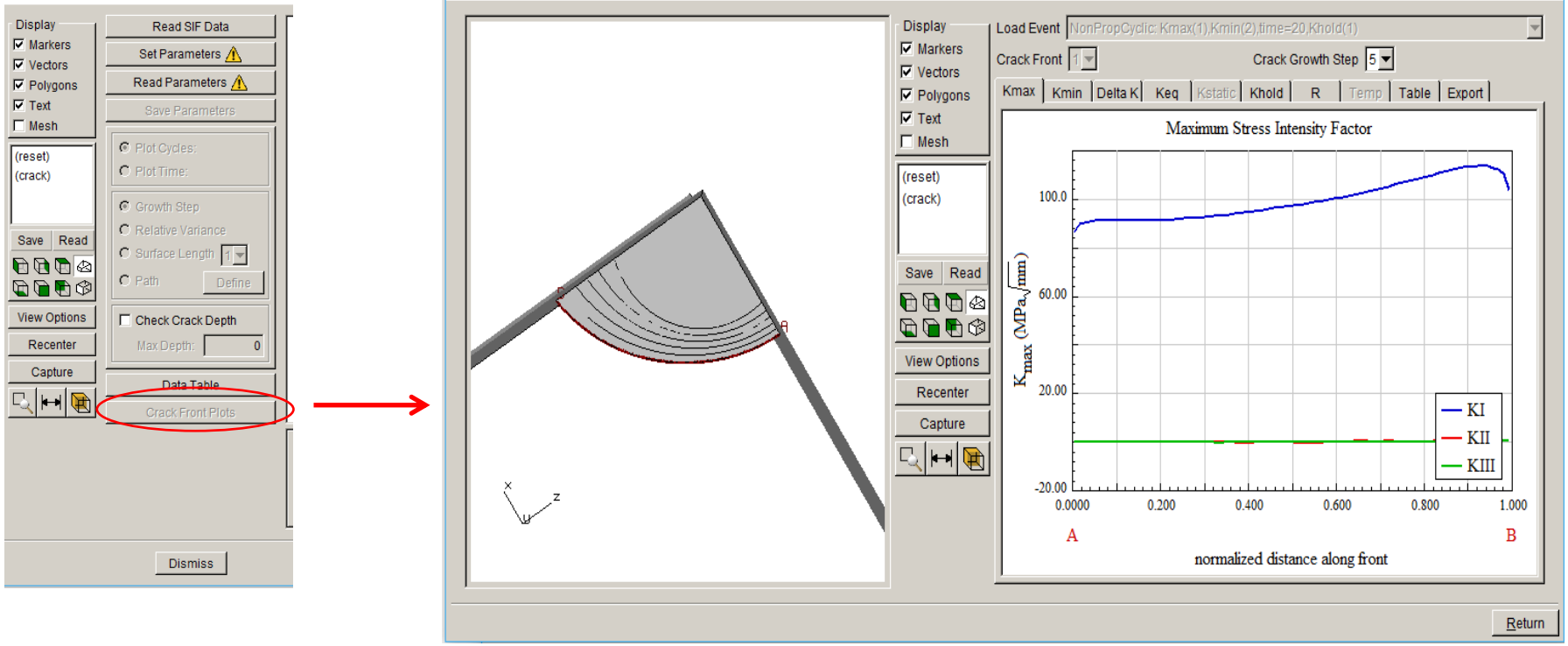
- Defining a Path





User Interface

- Crack Front Plots
  - display Kmax, Kmin, Delta K, Keq, Kstatic, Khold, R, and Temp for each crack front and for each growth step



Demo/Hands On (Homework): SIF History and Fatigue Life

End Part 10