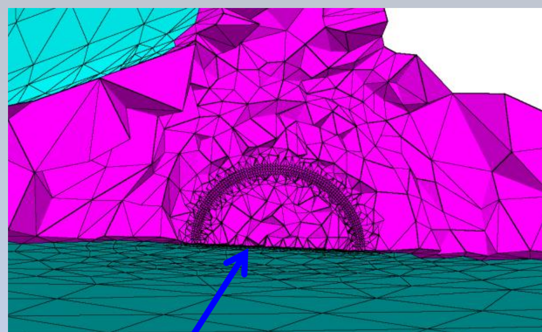
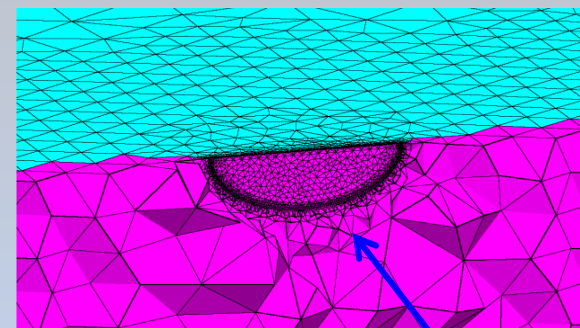
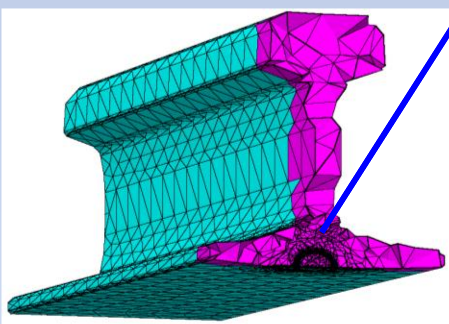
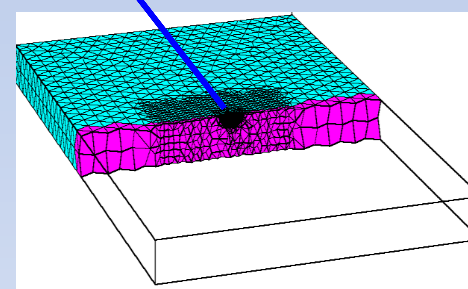
Case Studies on Mode-I Fatigue Crack Propagation Using Fully Unstructured Finite Elements









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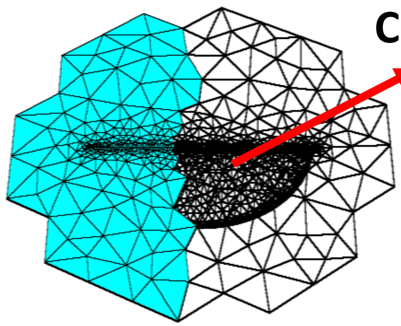
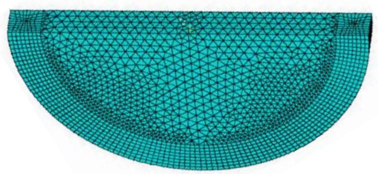
Outline

- ❑ Motivation and Needs for Crack Insertion Techniques
- ❑ Description of Crack Insertion Procedure
- ❑ Case Studies
  - ❑ Mode-I surface crack in finite thickness plate
  - ❑ Mode-I surface crack in a rail base
    - ➢ *Problem Description*
    - ➢ *Insertion of Crack into uncracked structure*
    - ➢ *Stress Intensity Factor Solutions*
    - ➢ *Prediction of Crack Propagation Patterns and Lives*
    - ➢ *Comparison with Results in Literature*
- ❑ Summary and Conclusions

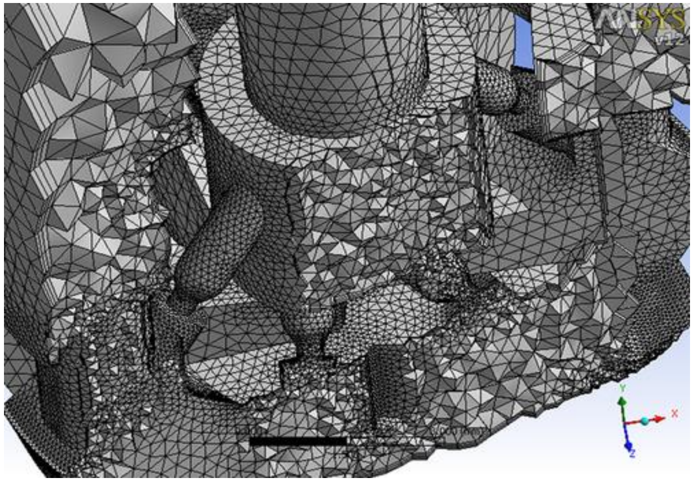
Motivation

- Modeling of three dimensional cracks
- Generating its finite element mesh





Three dimensional crack



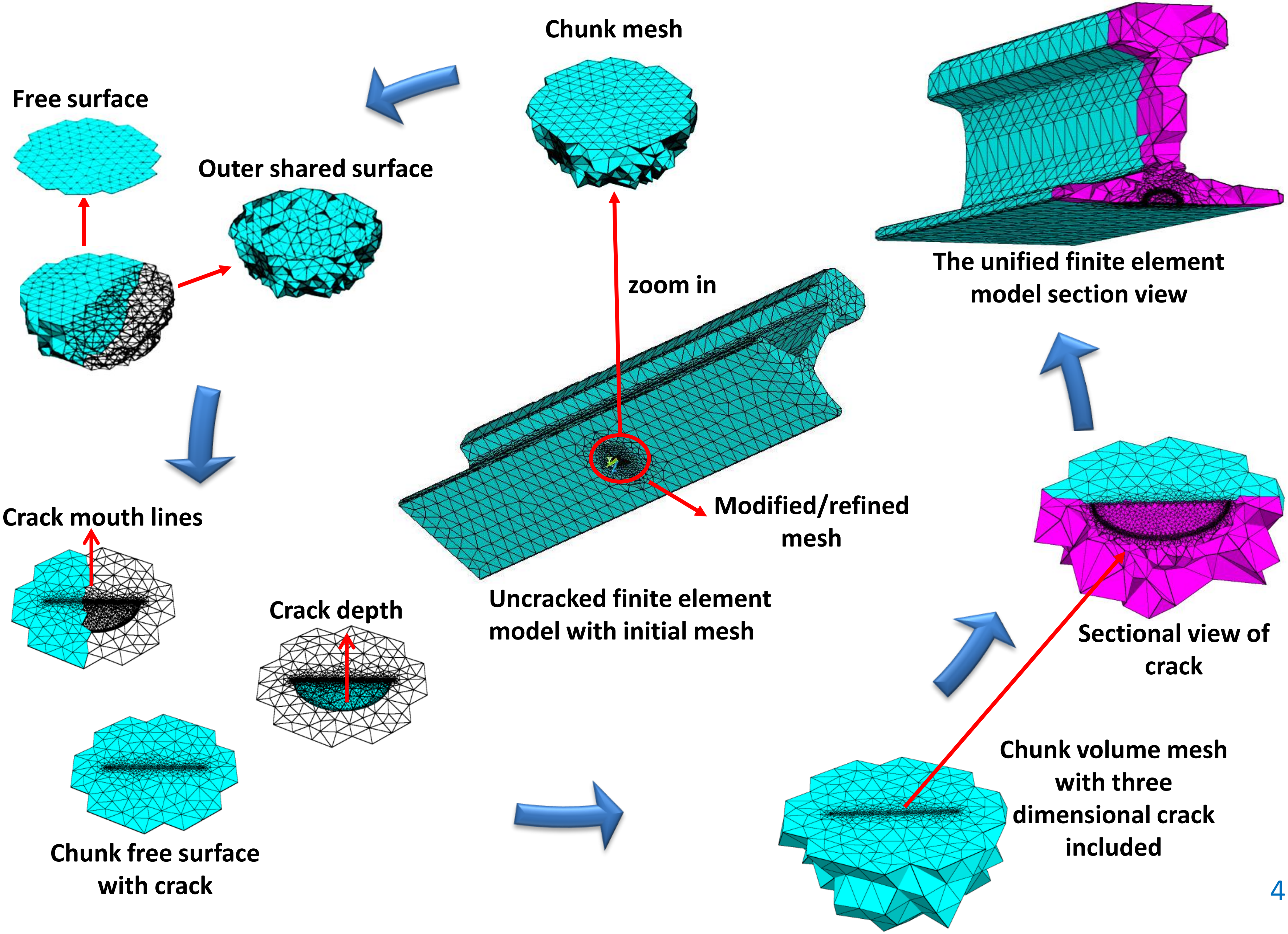
Modeling and Meshing

Depending on the complexity of geometry

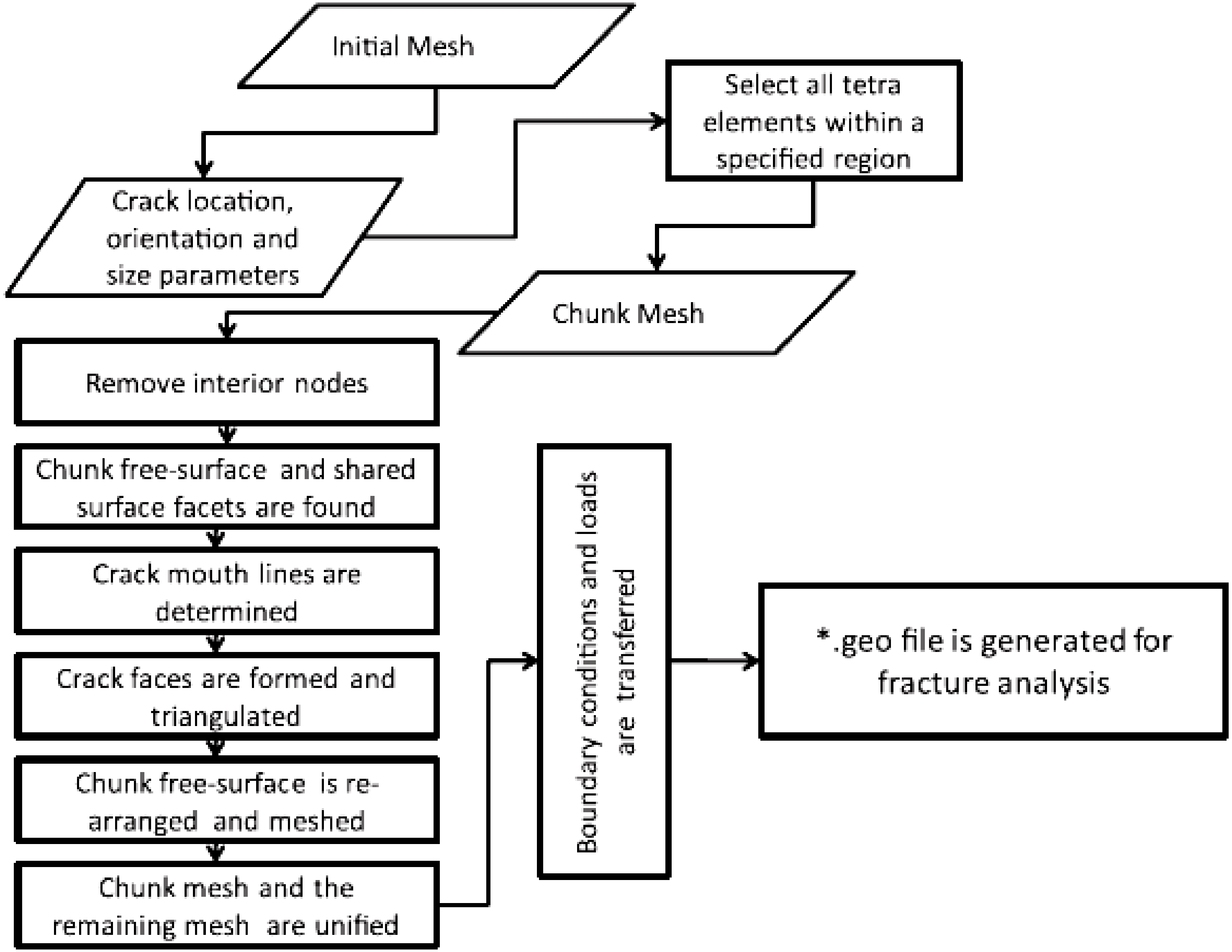
Appreciable time and effort

Ref: [1] http://wildeanalysis.co.uk/cfd/software/ansys/workbench/meshing

Crack Insertion Procedure

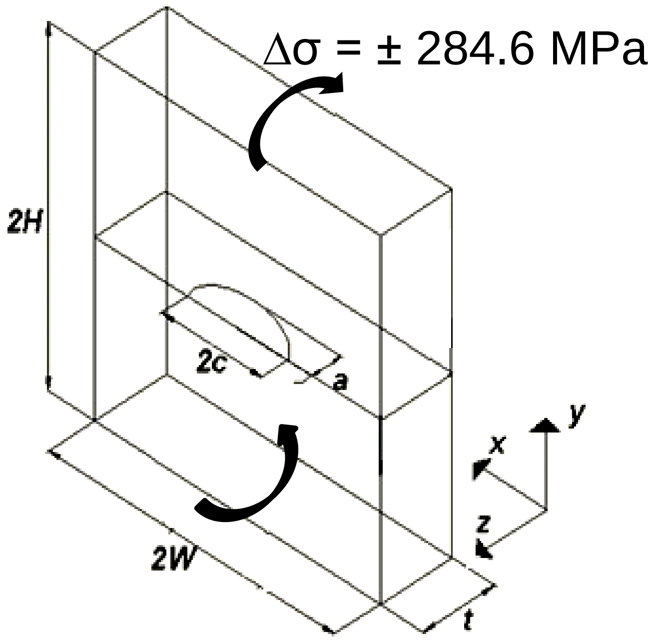


Process Map of Crack Insertion Procedure



Case Study : Mode-I surface crack in finite thickness plate

Problem Description



A plate made of martensitic P91 steel containing a surface crack was used in Reytier experiment.

The fracture problem data are taken from the literature (Reytier, 2004).

2W = 350 mm,
2H = 590 mm
t = 30 mm
a = 6.9 mm
c = 12.4 mm

Prediction of crack is attempted using crack growth law, e.g., Paris-Erdogan law;

$$\frac{da}{dN} = C(\Delta K)^n \qquad C = 7.1*10^{-7} \frac{mm}{cycle\left(MPa\sqrt{m}\right)^n}$$

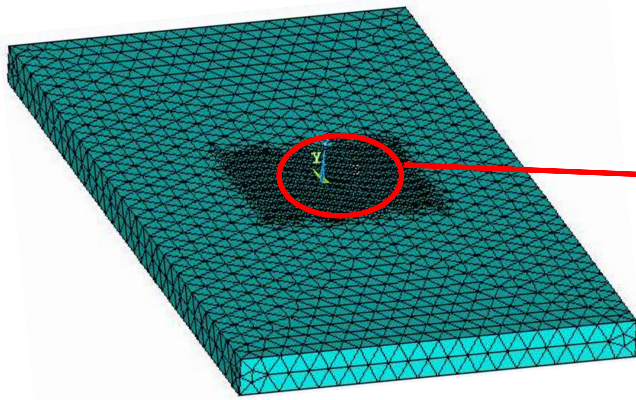
n=1.85,

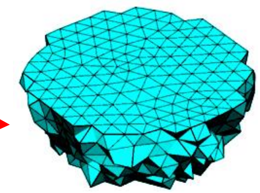
da/dN is in mm/cycles and

ΔK is in $MPa \cdot m^{1/2}$

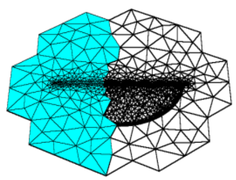
•**Ref [2] :** Reytier, M., "Fatigue crack growth in large cracked plates of martensitic P91 steel at 550 ºC", Power Plant Oper Mainten Mater Issue., 3(2):1–10; 2004.

Insertion of Crack into uncracked structure





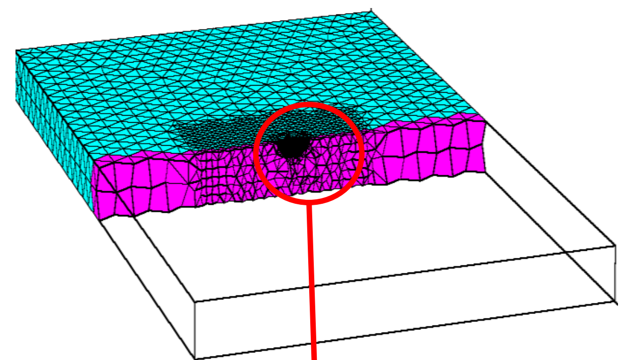
Chunk mesh

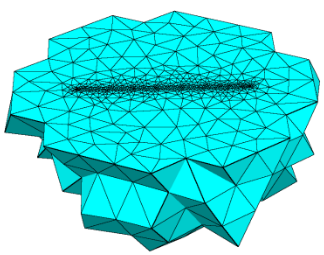


Crack mouth lines

Crack mouth line, boundaries of the outer free-surface are regenerated and meshed by using Triangle© code

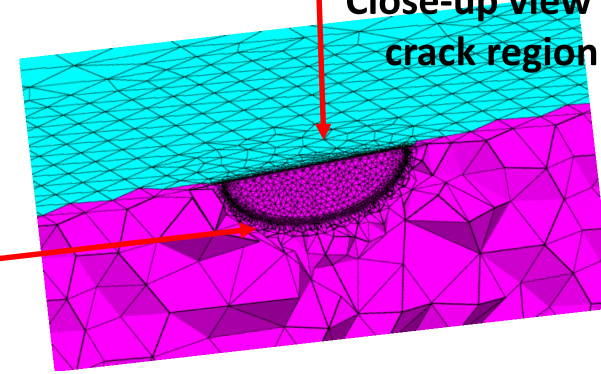
Sectional view of crack region





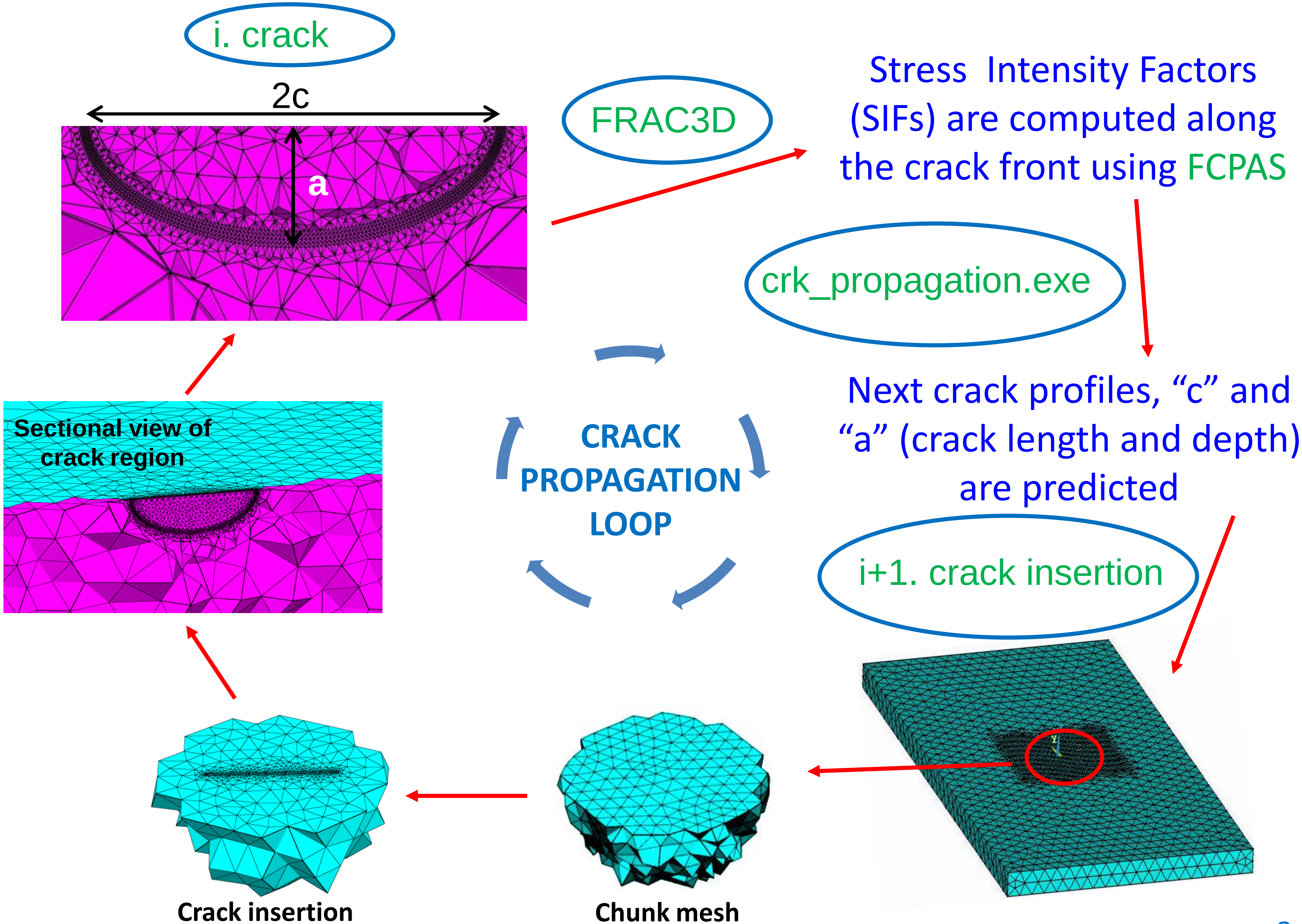
Volume meshing is performed with tetrahedral elements including refinement near crack front line by using three-dimensional meshing software ,Tetgen©

Close-up view of crack region

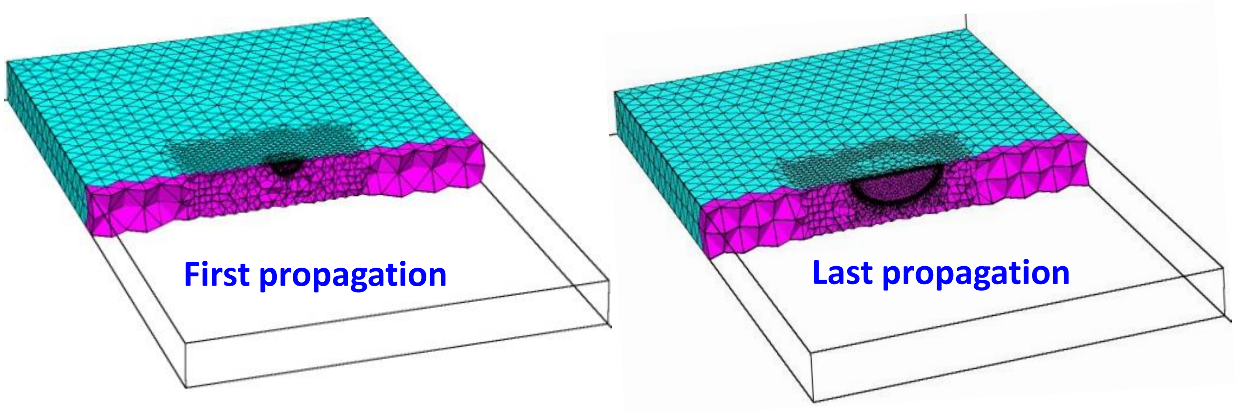


Stress Intensity Factors (SIFs) are computed along the crack front using FCPAS

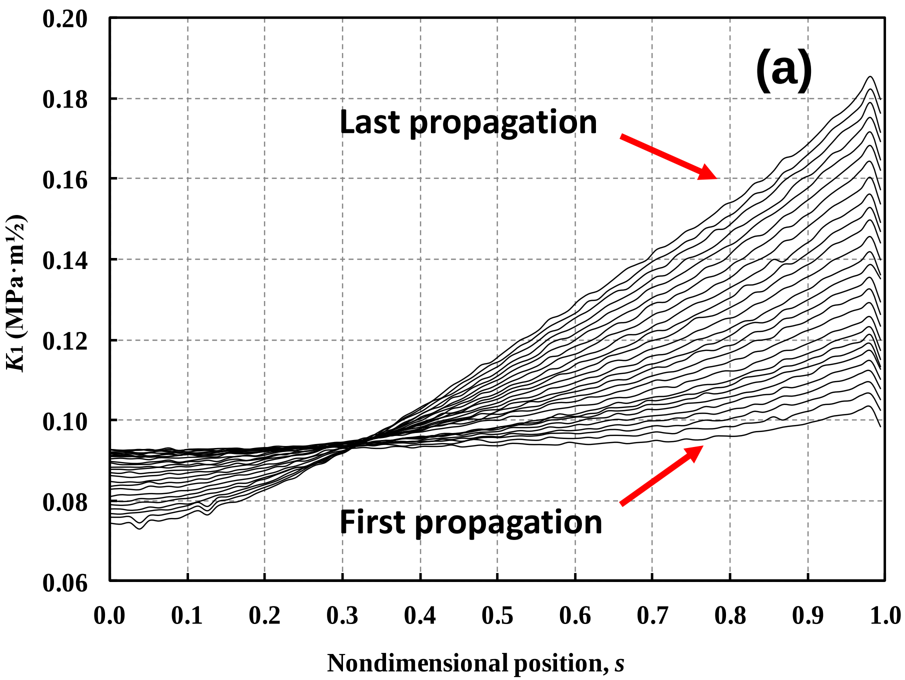
Fracture Analysis and Crack Propagation

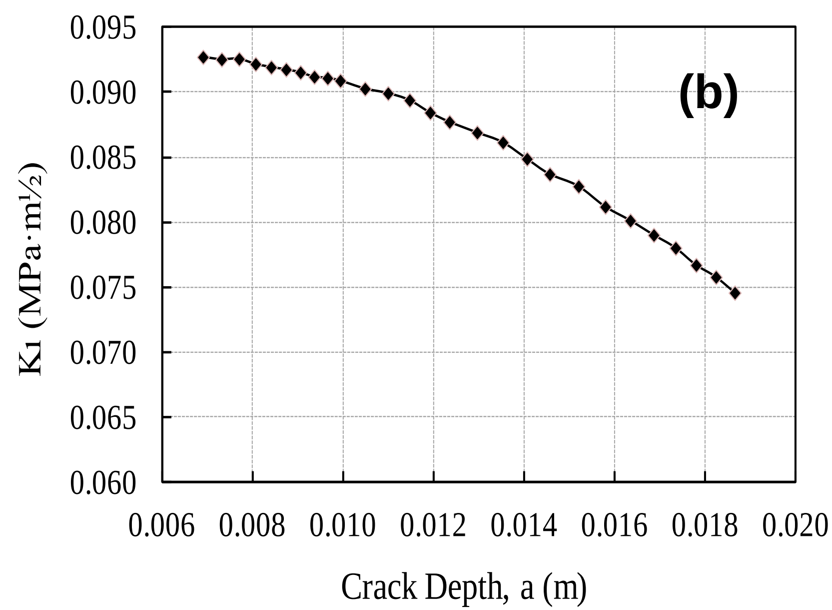


Stress Intensity Factor Solutions



The mode-I stress intensity factor solutions are performed using three dimensional enriched crack tip elements included in FCPAS.

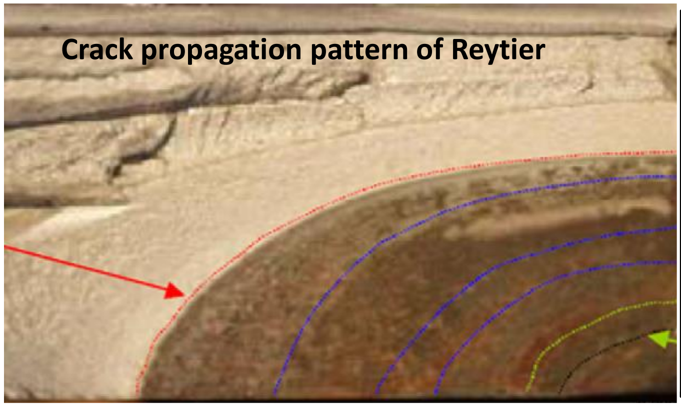


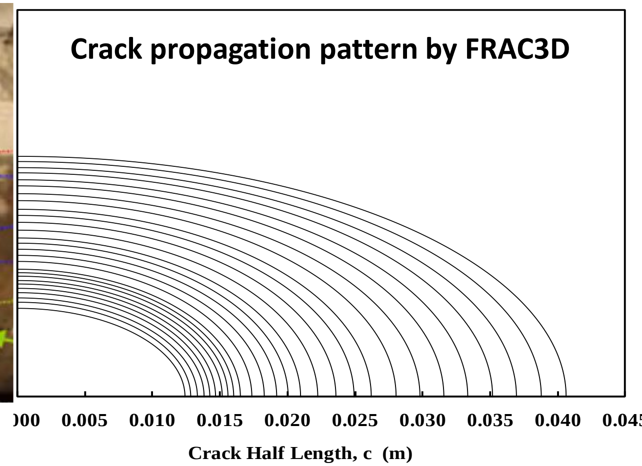


Mode-I stress intensity factors during crack growth, **(a)** Variation as a function of nondimensional crack front position, **(b)** At the crack depth point, $\Delta\sigma$= 1 MPa.

Prediction of Crack Propagation Patterns and Lives

Crack propagation analyses are also performed using modules in FCPAS (Fracture and Crack Propagation Analysis Software).

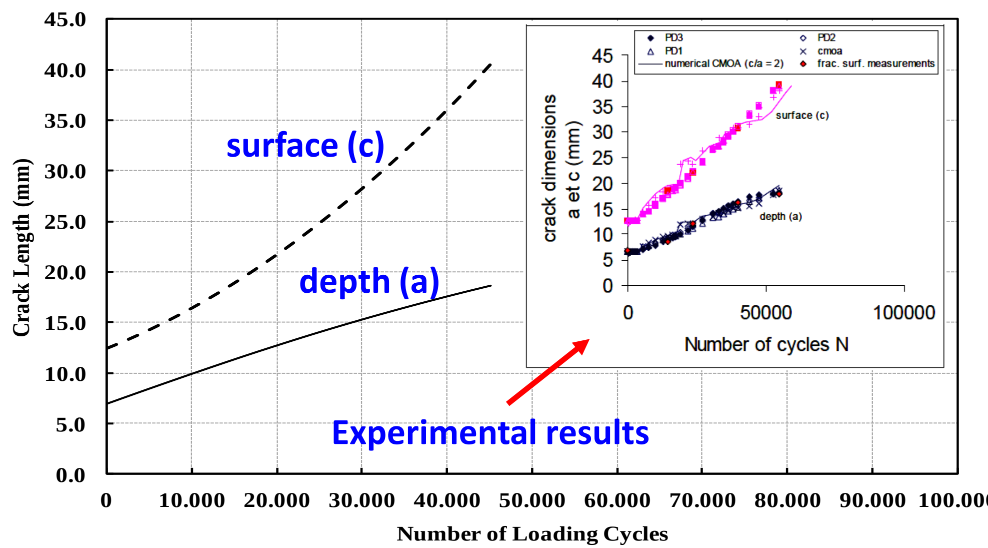




Comparison of crack propagation patterns between observed experimentally and numerically.

Variation of crack length at the depth point as a function of loading cycles.

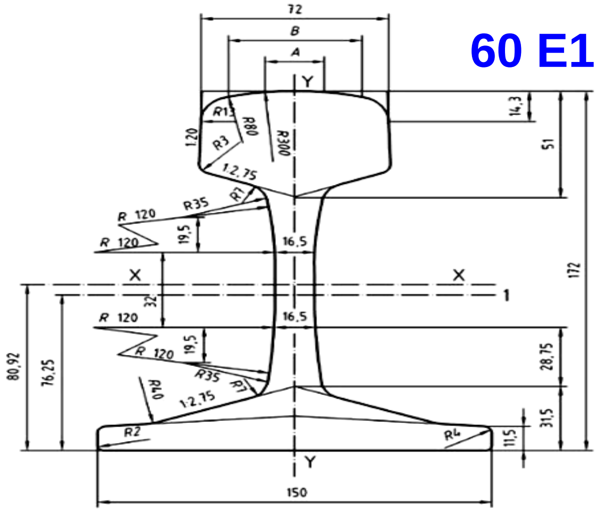
Experimentally observed results are also given.



•**Ref [2] :** Reytier, M., "Fatigue crack growth in large cracked plates of martensitic P91 steel at 550 ºC", Power Plant Oper Mainten Mater Issue., 3(2):1–10; 2004.

Case Study : Mode-I surface crack in a rail base

Problem Description

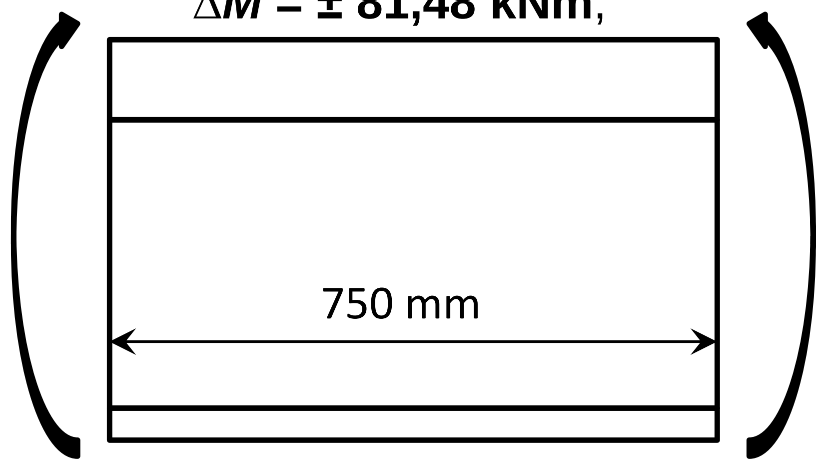


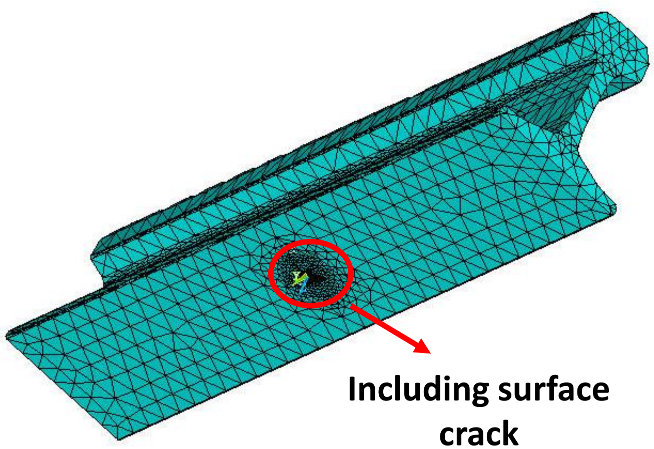
60 E1 (UIC 60)

Related Standart: EN 13674-1 / UIC 860-0

Pure bending moment is applied

$\Delta M = \pm$ **81,48 kNm**,





Assessment of Fatigue Cracks in Rails

The initial crack dimensions are;

a = 0.5 mm and c = 0.5 mm.

Material constants are;

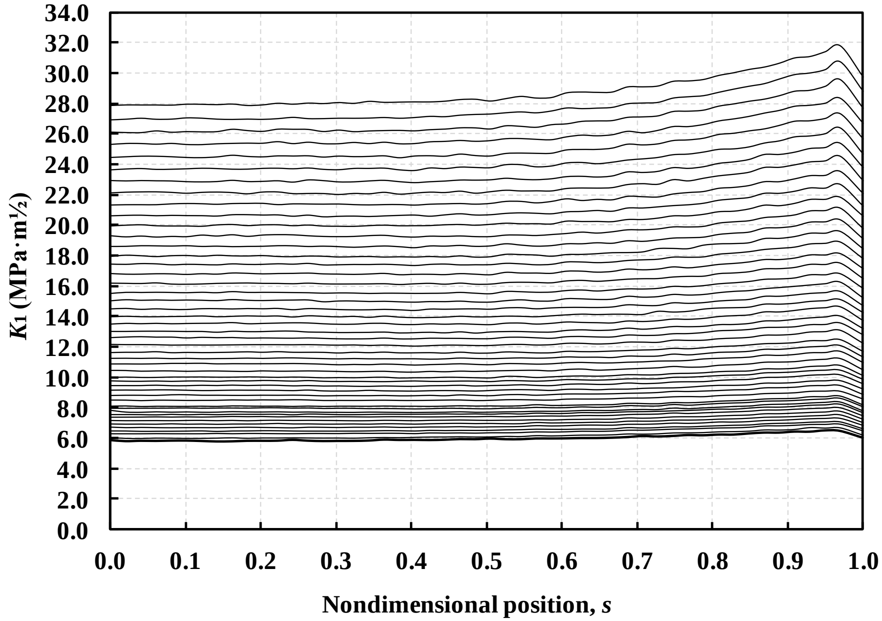
$$C = 3.3 * 10^{-10} \frac{mm}{cycle\left(MPa\sqrt{m}\right)^n}, \quad n = 2.63$$

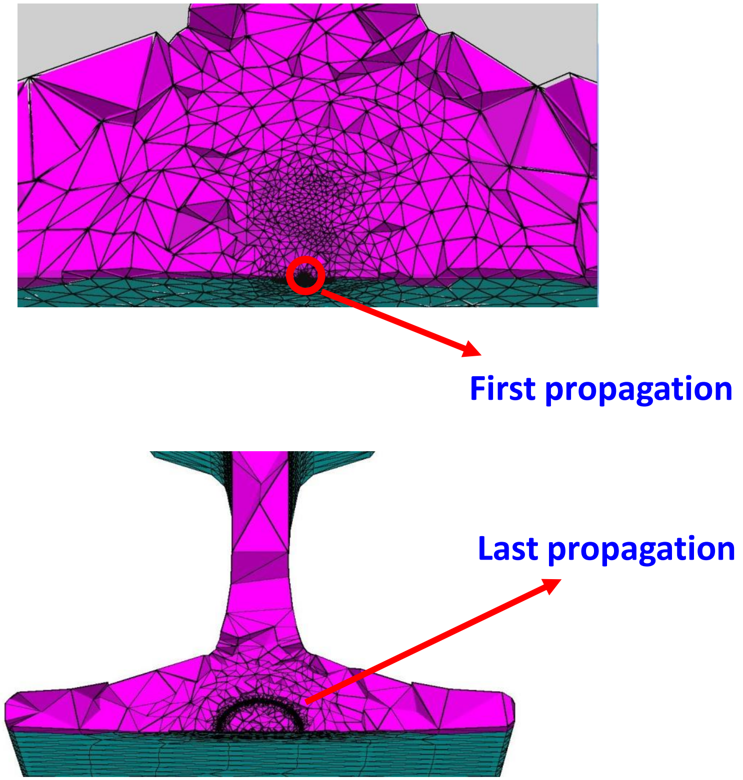
da/dN is in mm/cycles

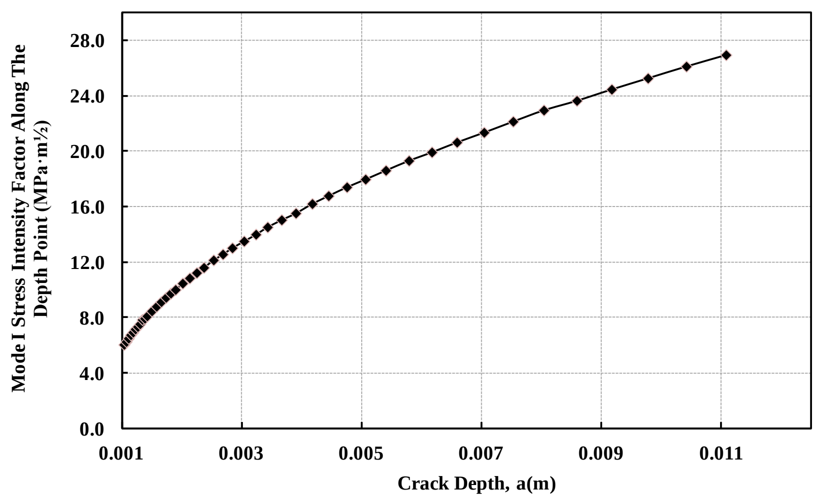
•**Ref [3] :** Kotsikos, G., Grasso, M., " Assessment of Fatigue Cracks in Rails ", Procedia - Social and Behavioral Sciences 00, 000–000; 20011.

Stress Intensity Factor Solutions

Mode-I stress intensity factors during crack growth

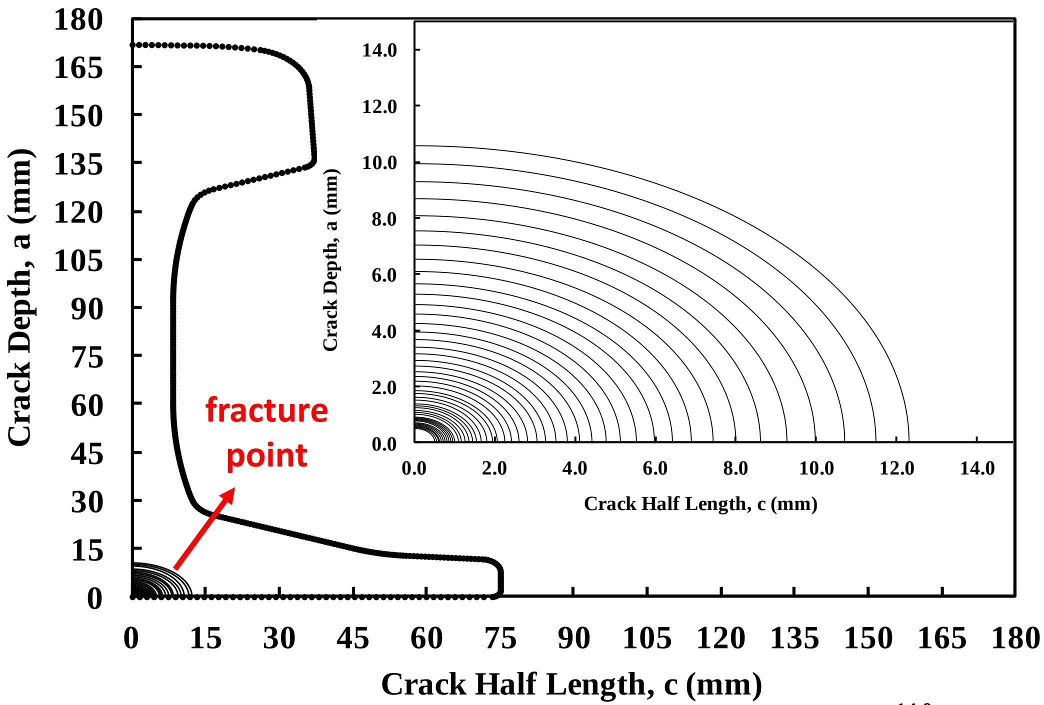






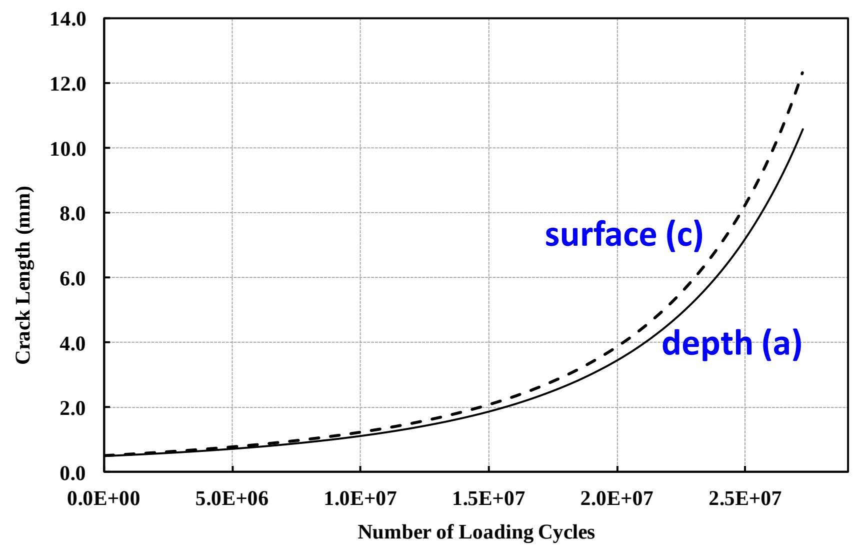
Variation of mode-I stress intensity factors during crack growth as a function of crack depth.

Prediction of Crack Propagation Patterns and Lives



Plots of crack profiles during crack growth.

Variations of crack lengths at the free-surface and the depth point during crack growth as a function of loading cycles.



Summary and Conclusions

- In this study, applications are presented that demonstrate the crack insertion procedure for two different fatigue crack propagation problems.
- It is shown that the procedure described above can be efficiently applied to mode-I fatigue crack propagation problems using fully unstructured mesh by employing a crack insertion procedure and tetrahedral enriched elements.
- Enriched finite elements used in FCPAS allow computation of SIFs and simulation of crack growth in three-dimensional structures accurately and efficiently
- Computed SIFs and predicted crack propagation patterns and lives using FCPAS agree well with experimental failure observations in literature
- The presented procedure can be extended to mixed-mode crack propagation problems that involve growth of crack surfaces in a non-planar manner.

Acknowledgements

✓*Authors are thankful to The Scientific and Technological Research Council of Turkey (TUBITAK) for the financial support during FCPAS Project.*