FCPAS – Fracture &Crack Propagation Analysis System

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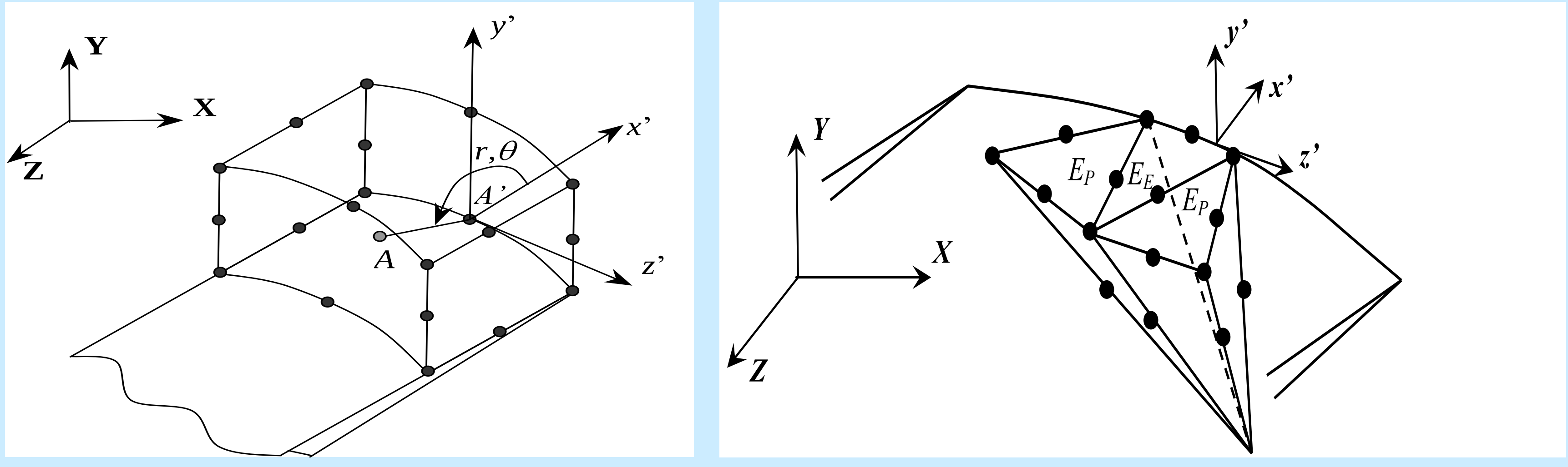
Modeling of Three-Dimensional Fracture Problems Using FCPAS: Application on a Surface Crack Problem

Abstract

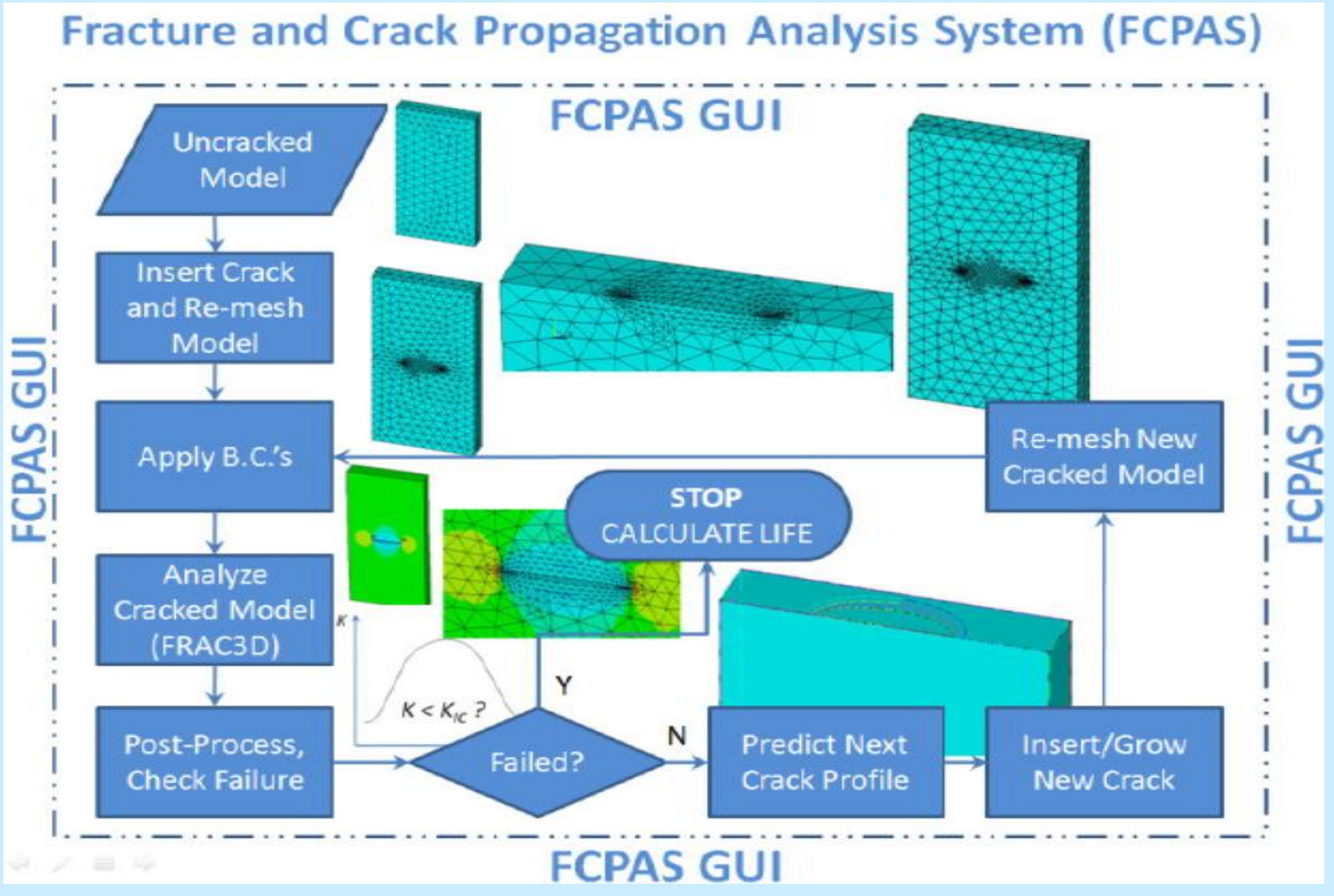
Most engineering parts truly have three-dimensional geometrical and load characteristics from a mechanics perspective. Therefore, in the presence of a crack in such a structure, three-dimensional fracture analysis capability is very much needed to be able to assess its fail-safe condition or its remaining life. Many methods and procedures available today require extensive amount of pre- and post-processing times to, respectively, build an appropriate three-dimensional fracture model and extract important fracture parameters such as stress intensity factors [1]. In this paper, FCPAS (Fracture and Crack Propagation Analysis System), an efficient and easy-to-use three-dimensional fracture analysis software, is introduced to model and analyze three-dimensional fracture problems accurately. FCPAS consists of different modules for model preparation/conversion, settings of analysis parameters, analysis/solution and post-processing/visualization of results. Two types of three-dimensional fracture models can be generated and analyzed: 1) fracture models built within commercially available software ANSYS™ and converted into FCPAS format, and 2) an unstructured mesh without a crack taken as input and a three-dimensional crack of desired elliptical shape inserted into it. The fracture analysis/solution is performed by using enriched finite elements along the three-dimensional crack front that eliminate the need of preparing special mesh in this region and laborious post-processing of the finite element solution. As an example, a corner crack contained in a three-dimensional part is presented to demonstrate the procedure of building the model within ANSYS and solving/post-processing using FCPAS. The obtained results are compared with those available in the literature.

Three-Dimensional Enriched Crack Tip Elements



Introduction

Among the numerical methods used in analyses of three-dimensional crack problems, the finite element method has become the most commonly used technique to solve such problems. This and most other techniques that exist today have special mesh requirements to be met for an "accurate" fracture analysis and may involve laborious post-processing efforts to compute the desired fracture parameters such as stress intensity factors (*K*) and strain energy release rates (*G*) [2]. For a general three-dimensional fracture mechanics problem, these meshing and post-processing steps may take significantly large times and efforts, making the analyses of such problems impractical, perhaps impossible for some problems involving complicated part or crack geometry. It is well known that although some problems can adequately be approximated by two-dimensional methods and analysis tools, most real problems require "truly" three-dimensional methods and tools to be able to assess the structure's fail/safe condition or its remaining life from a fracture mechanics perspective. Thus, three-dimensional fracture methods and analysis tools that are "accurate, efficient and easy-to-use" are very much needed. This study presents a general-purpose three-dimensional fracture mechanics analysis software, FCPAS – **F**racture and **C**rack **P**ropagation **A**nalysis **S**ystem. The main objective for development of FCPAS is to provide an accurate and easy-to-use analysis environment for researchers who are interested in solving three-dimensional linear elastic fracture mechanics problems efficiently. Having performed the solution and obtained the SIFs on the front of a three-dimensional crack, the SIF distribution can be plotted and deformed shape and stress contours can be visualized via incorporation of Visualization Toolkit [3].



Fracture and Crack Propagation Analysis System (FCPAS)

FCPAS GUI

Uncracked Model

Insert Crack and Re-mesh Model

Apply B.C.'s

Analyze Cracked Model (FRAC3D)

Post-Process, Check Failure

Failed?

$K < K_{Ic}$?

Y

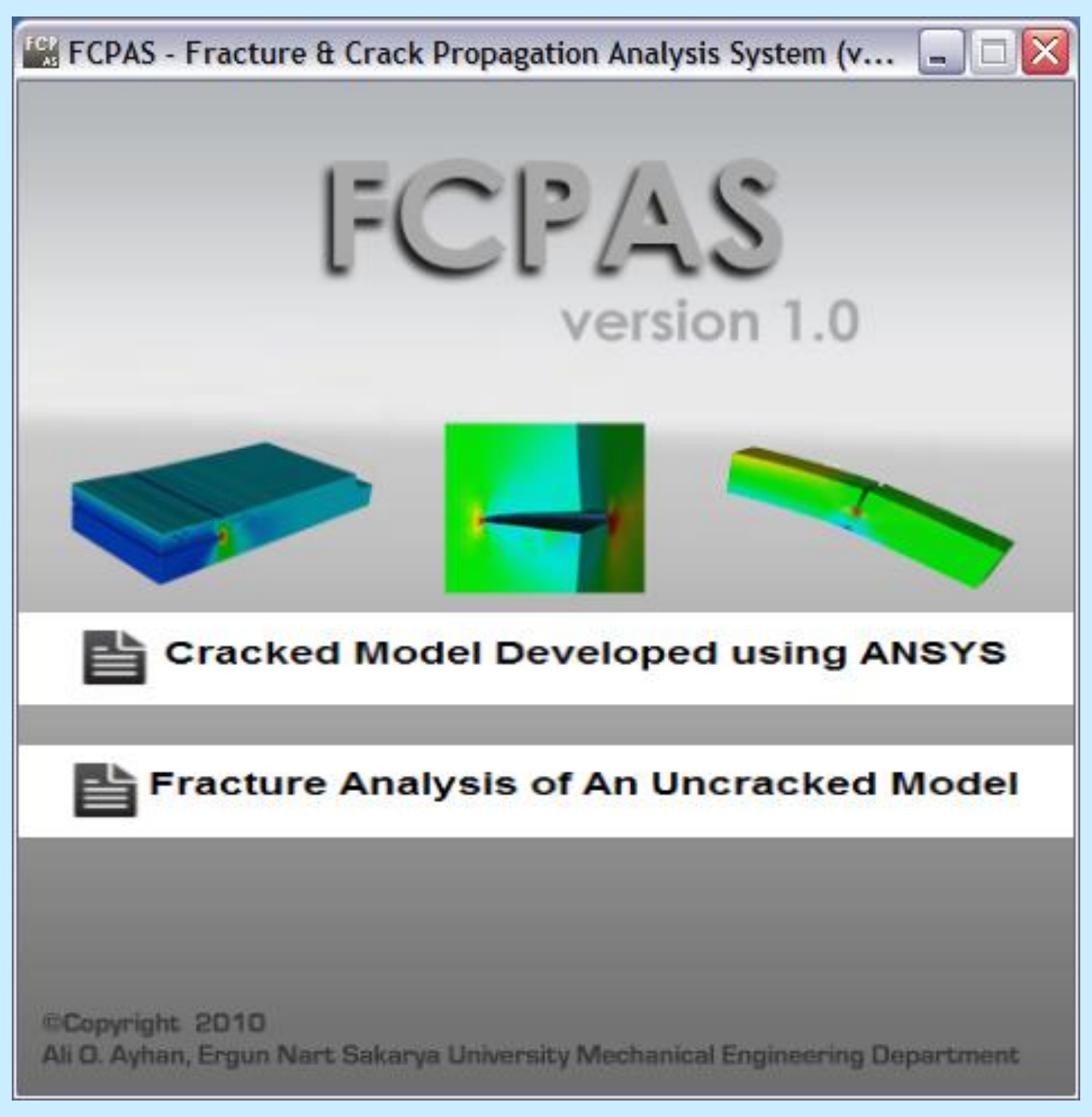
N

STOP CALCULATE LIFE

Predict Next Crack Profile

Insert/Grow New Crack

Re-mesh New Cracked Model



FCPAS

version 1.0

Cracked Model Developed using ANSYS

Fracture Analysis of An Uncracked Model

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Material and Method

The main and most important method used within FCPAS is the three-dimensional enriched finite element technique incorporated within the solver part of FCPAS, FRAC3D. Other modules of FCPAS either carry out pre-or post-processing related tasks involved in a finite element analysis.

Three-Dimensional Enriched Finite Element Formulation

In the above figure, 20-noded hexahedral and 10-noded tetrahedral enriched crack tip elements having an edge or a point on an arbitrarily oriented crack front are shown. It should be noted that the crack front is fully surrounded by these types of elements with edge or point-touches to the crack front. The stress intensity factors along a given crack front are included in the element finite element formulation as unknowns in addition to nodal displacements and solved for directly in the solution phase. The finite element displacement formulation for enriched elements is given below [4].

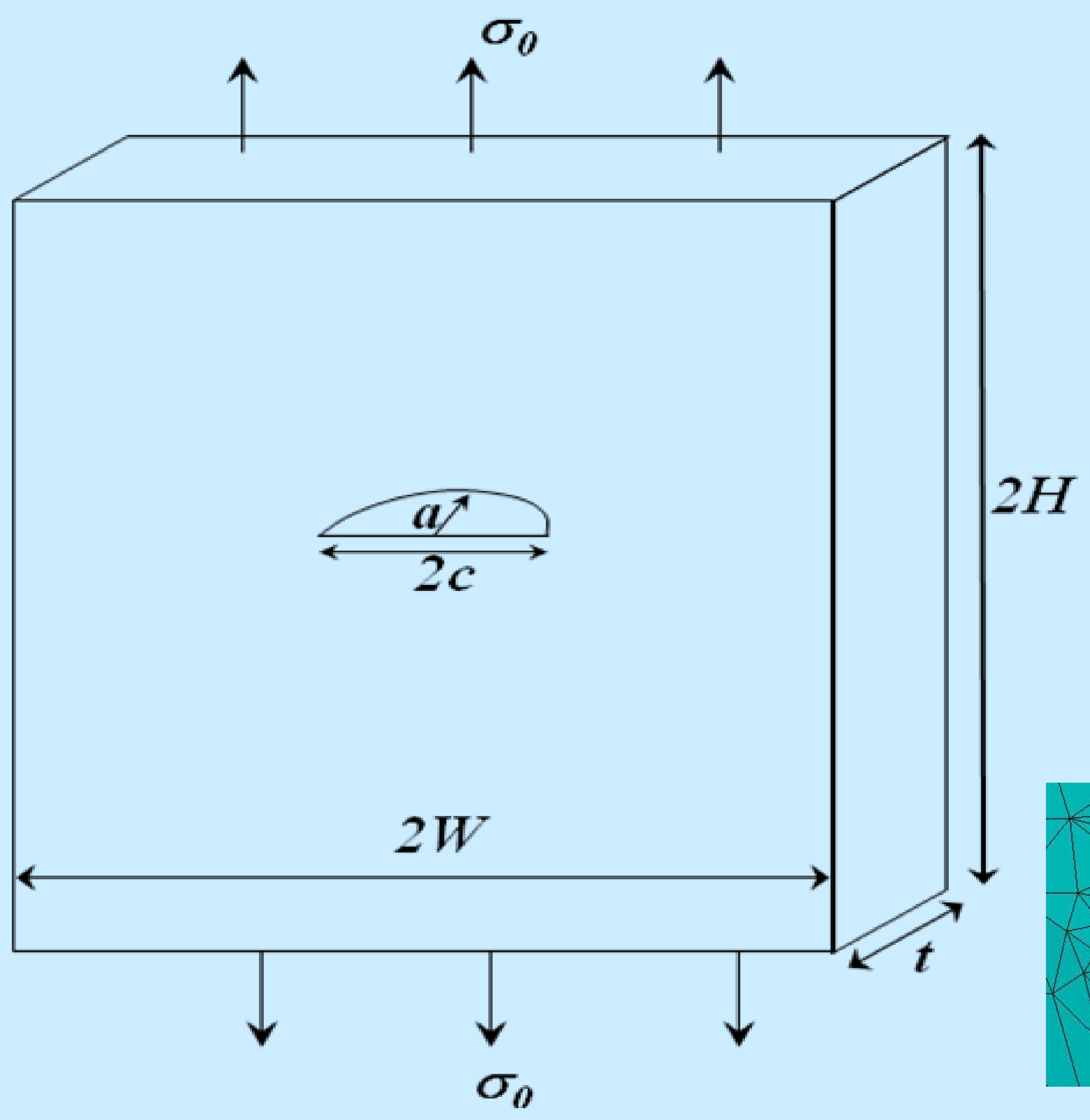
$$
\begin{aligned}
u(\xi,\eta,\rho) = {} & \sum_{j=1}^{m} N_j(\xi,\eta,\rho)u_j + Z_0(\xi,\eta,\rho)\left(f_u(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) f_{uj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_I^i \right) \\
& + Z_0(\xi,\eta,\rho)\left(g_u(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) g_{uj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_{II}^i \right) \\
& + Z_0(\xi,\eta,\rho)\left(h_u(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) h_{uj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_{III}^i \right)
\end{aligned}
$$

$$
\begin{aligned}
v(\xi,\eta,\rho) = {} & \sum_{j=1}^{m} N_j(\xi,\eta,\rho)v_j + Z_0(\xi,\eta,\rho)\left(f_v(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) f_{vj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_I^i \right) \\
& + Z_0(\xi,\eta,\rho)\left(g_v(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) g_{vj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_{II}^i \right) \\
& + Z_0(\xi,\eta,\rho)\left(h_v(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) h_{vj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_{III}^i \right)
\end{aligned}
$$

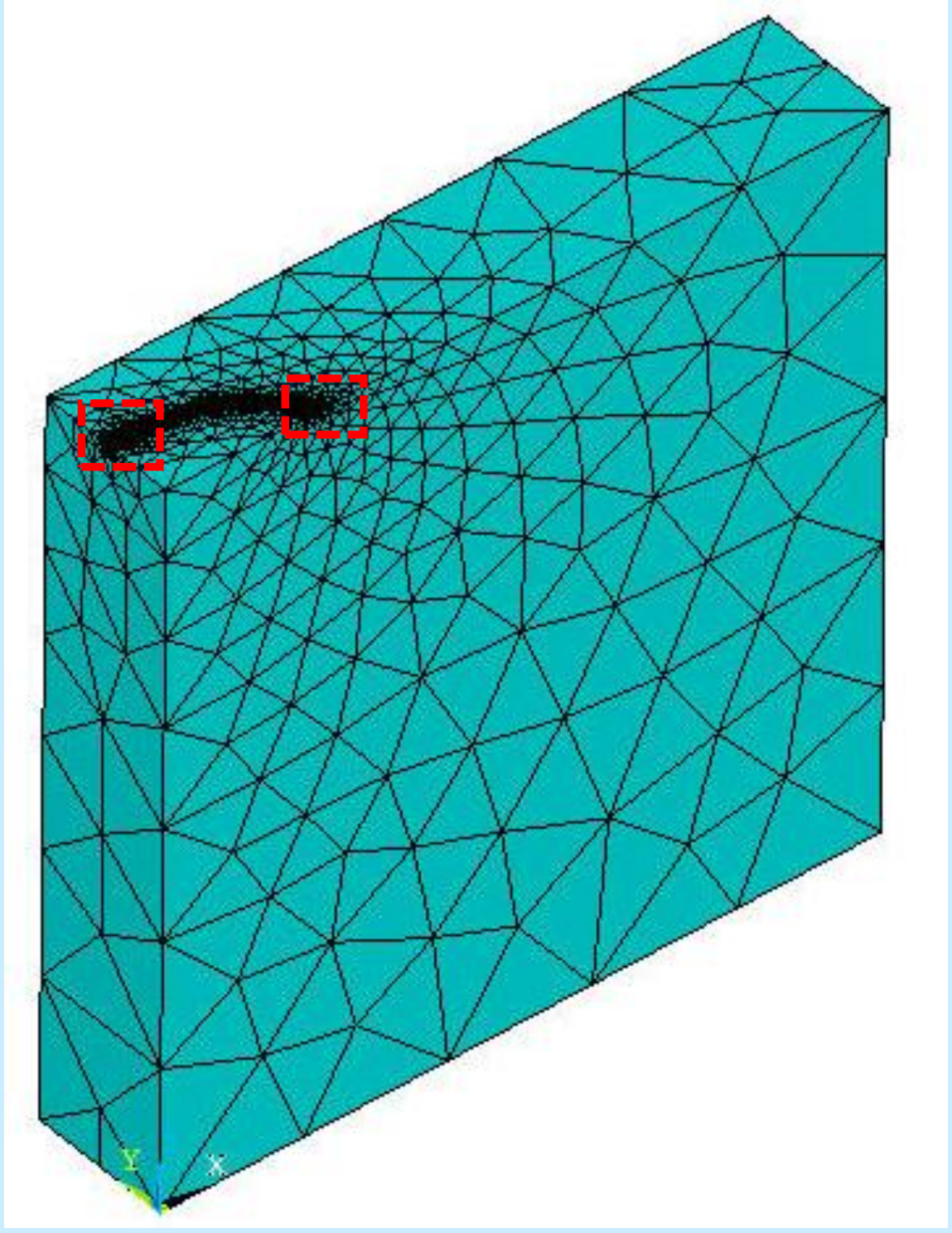
$$
\begin{aligned}
w(\xi,\eta,\rho) = {} & \sum_{j=1}^{m} N_j(\xi,\eta,\rho)w_j + Z_0(\xi,\eta,\rho)\left(f_w(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) f_{wj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_I^i \right) \\
& + Z_0(\xi,\eta,\rho)\left(g_w(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) g_{wj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_{II}^i \right) \\
& + Z_0(\xi,\eta,\rho)\left(h_w(\xi,\eta,\rho) - \sum_{j=1}^{m} N_j(\xi,\eta,\rho) h_{wj} \right)\left(\sum_{i=1}^{ntip} N_i(\Gamma)K_{III}^i \right)
\end{aligned}
$$

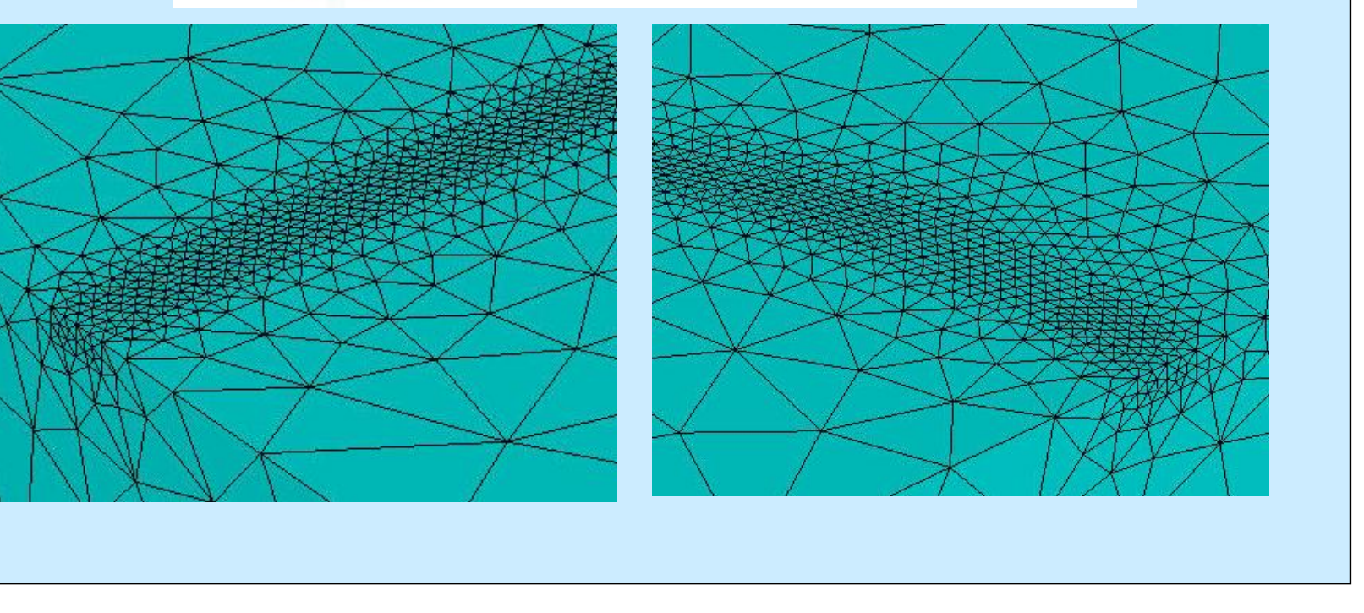
Numerical Examples

Surface Crack in a Plate Under Uniform Tension



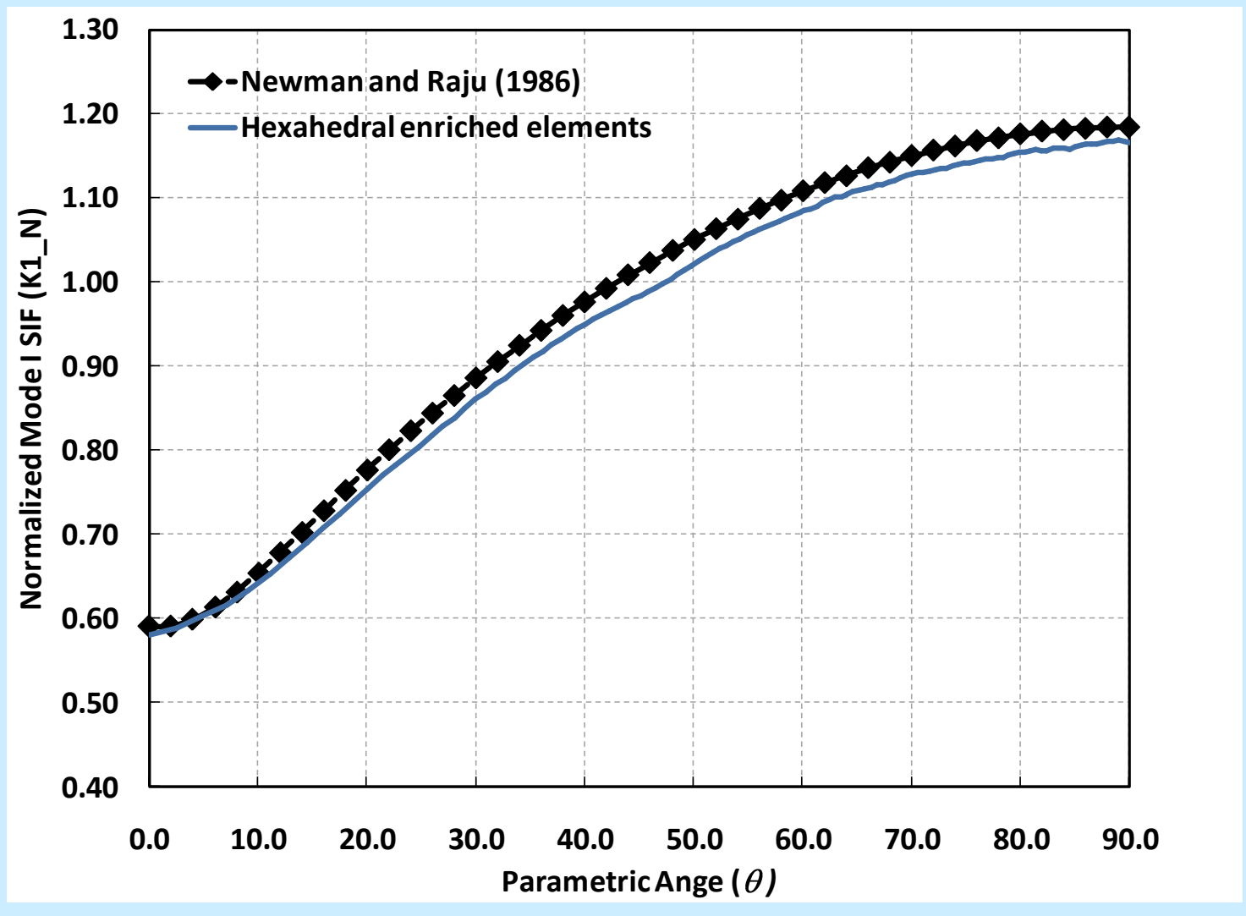
Finite Element Mesh

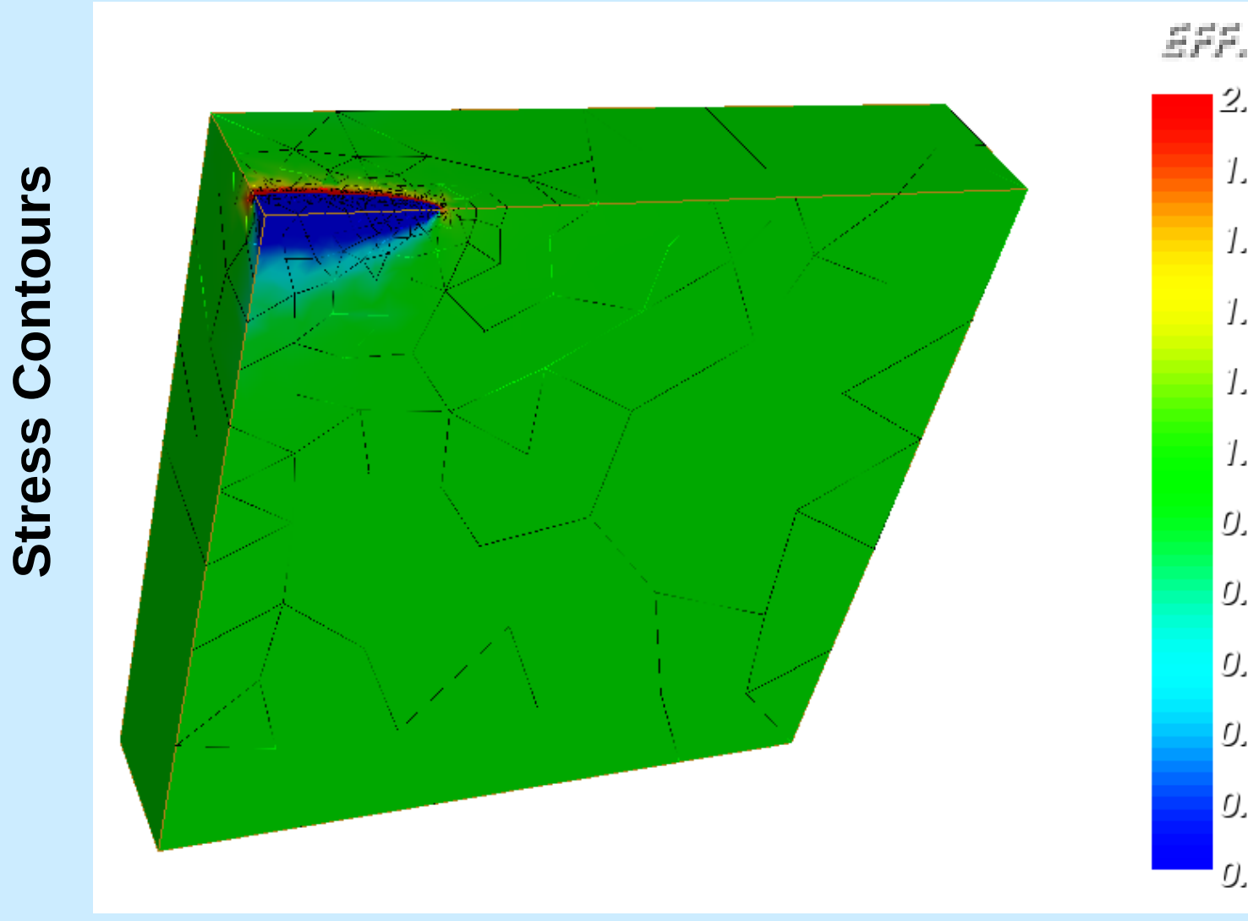




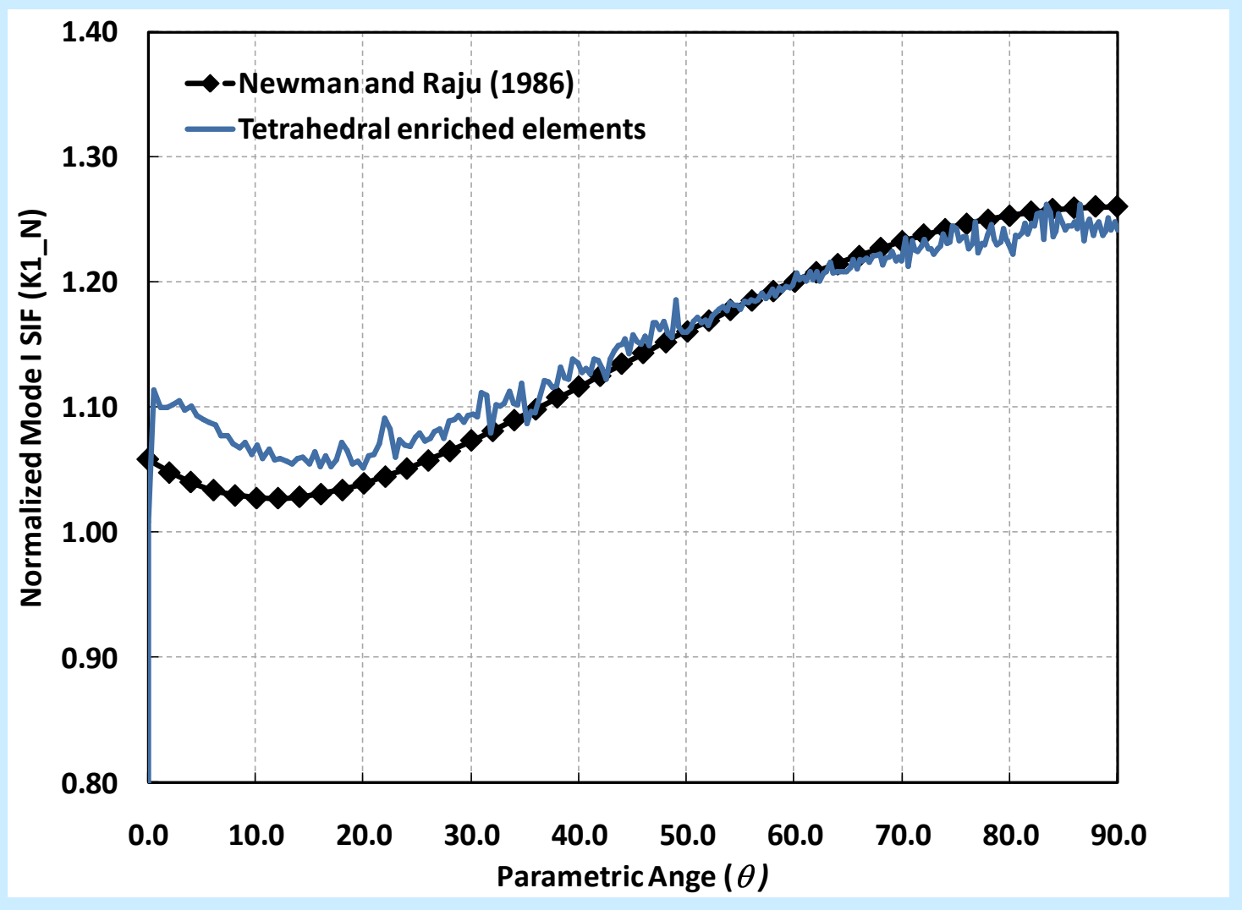
Numerical Examples

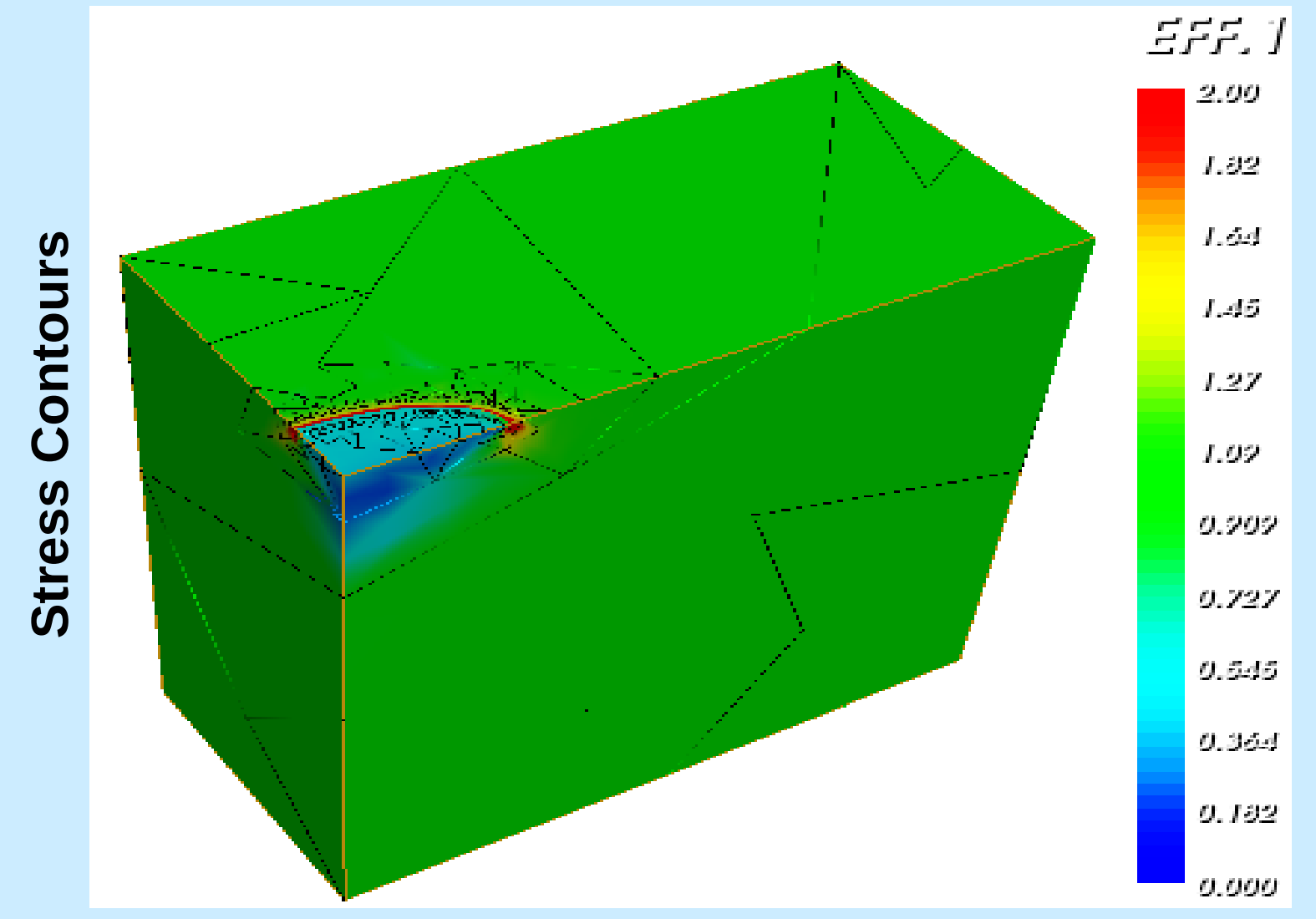
a/c = 0.2





a/c = 0.5





Conclusion-Outlook and Acknowledgement

Applications are presented that demonstrate the usage and results obtained for a surface crack in a finite-thickness plate under uniform tension. This problem has received great level of interest in the last two decades starting with a surface crack in a homogeneous medium and later other materials such as functionally graded media. Here, the application of FCPAS is demonstrated on a semi-elliptical surface crack problem and the results obtained are compared to those available in the literature. The comparisons showed very good agreement with reference solutions [5]. Therefore, it is concluded that FCPAS software and the three-dimensional enriched elements yield accurate solutions for three-dimensional fracture problems.

Future studies will include further automation of the processes involved within FCPAS methodology and developing the capabilities for automated crack growth analyses for three-dimensional cracks in plates.

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References

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Sakarya University, Department of Mechanical Engineering   http://www.sakarya.edu.tr/~ayhan/FCPAS