Development of FEAM Analysis Code GCS1 for Elasto-Plastic Fracture Mechanics

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1. Introduction

The general crack solver (GCS1) code, which was developed in this study based on finite element alternating method, has advantages in saving labor cost because it is not necessary to include cracks in the finite element mesh. The finite element alternating method (FEAM) has been known as an effective method for obtaining accurate fracture mechanics parameters such as stress intensity factors [1, 2].

The required analytical solution for an arbitrarily curved crack in an infinite isotropic plate is obtained by solving the integral equations formulated by Cheung and Chen [3, 4]. Park, Kim and Atluri [5, 6] solved three-dimensional cracks and multiple curved cracks with the method. Kim and Park [7] further extended the method for multiple curvilinear cracks in an orthotropic plate.

The GCS1 code developed in this paper can be applied to obtain elasto-plastic stress fields for two- dimensional and three-dimensional cracks. Elasto-plastic stress fields can be obtained by using the initial stress method proposed by Nayak and Zienkiewicz [8]. Nikishkov and Atluri [9] first proposed the algorithm for elasto-plastic analysis in the finite element alternating method. Here their algorithm was used after modification and the necessary analytical solution was the solution for curved cracks. Also this code is very effective for fatigue crack growth simulation of multiple curved cracks. In order to verify the usefulness of the developed GCS1 code, several example problems are solved.

2. Characteristics of GCS1

2.1 Analysis Scope of code

The GCS1 code is written in FORTRAN 77, while the code for graphical user interface is written in Visual C++. The developed code can consider the following problems:

1. Problems to obtain Mode I and II stress intensity factors for arbitrary curved cracks in an isotropic or orthotropic plate (the maximum number of cracks is 2).
2. Problems to obtain Mode I, II and III stress intensity factors for an arbitrary 3-dimensional crack.
3. It is possible to import a foreign finite element mesh or initial stress fields obtained from other commercial programs.
4. Fatigue crack growth simulation can be carried out. In this case, there are alternative options. One is to obtain the crack length increment for the given number of loading cycles. The other is to obtain the number of loading cycles for the given crack growth increment (in such case, the maximum number of cracks is 2).
5. Elasto-plastic stress fields can be obtained for arbitrary curved cracks.
6. It is possible to compute J integral for arbitrary contours around the crack tip after elasto-plastic analysis.

2.2 Useful commands for application

Commands are the primary tools to communicate with the GCS1 program. About 40 commands were developed. Each command is designed to conduct a specific function, i.e., specifying data such as material properties or performing an action such as displaying a model. A typical command consists of command name and several arguments (which may be numeric value or alphanumeric value).

Analysis steps and commands required in each step are shown in Figure 1.

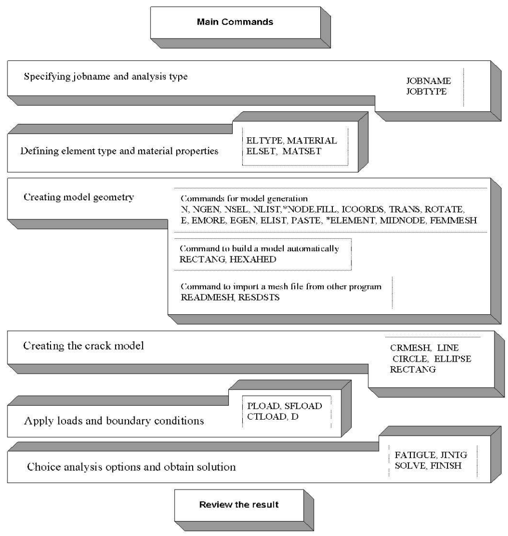

Figure 1. Main commands of GCS1.

Figure 2 shows a main window of the GCS1 code and a model generated by commands.

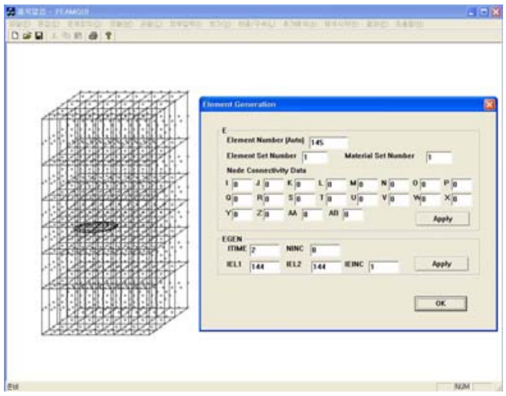

Figure 2. GCS1 menu layout.

3. Fatigue Crack Growth Simulation

First, the fatigue crack growth of a surface crack in an elbow pipe was simulated. The pipe geometry, crack configuration and loading condition are presented in Table 1. The Paris equation was chosen as the fatigue crack growth equation, where C=3.0E-13 and n=3.0 are used as recommended by Maddox [10] for a wide rage of structural steels. The initial ratio a/b of a semi-elliptical surface crack is 0.5, and the ratio of the crack depth and pipe thickness is 1/5. The stress analysis was done using ABAQUS and the resulting stress data was imported to the program as residual stresses in order to obtain the surface traction on the crack faces. And then, the stress intensity factors K_I were calculated at the crack front nodes.

Table 1 Analysis conditions for a surface crack in an elbow.

Classification	Variables	
Pipe geometry	Pipe length & diameter (mm)	4000.0 / 400.0
	Thickness (mm)	20.0
	Bend radius (mm)	6.0
Crack configuration	Shape	Elliptical surface
	Aspect ratio(b/a)	0.5 ~ 2.0
	Location	Inner Surface
Loading condition	Internal pressure	10 MPa

Substituting the stress intensity factors into the crack growth equation gives the crack growth increment at each crack front nodes and the nodes are advanced to new positions. A new layer of elements is defined along the crack front after growth. Then the analysis is repeated with the new crack mesh. Five crack advancements were performed and the stress intensity factor values along the crack front are illustrated in Figure 3. The maximum K_I is obtained at 90°.

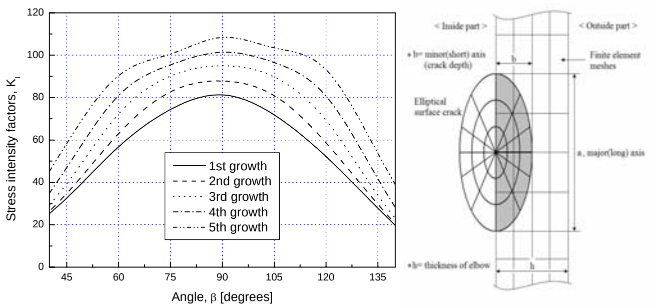

Figure 3. SIFs of a semi-elliptical crack in an elbow under cyclic loading condition.

4. Conclusion

The developed code can be applied to the technical problems such as arbitrary curved cracks, arbitrary 3-dimensional cracks, fatigue crack growth simulation, Elasto-plastic analysis, and so on. The user can easily obtain fracture mechanics parameters such as stress intensity factor and J integrals. The accuracy and efficiency of the developed code was demonstrated by solving example for finite and infinite bodies. And it can be noted that the developed code can be used as an effective tool to obtain fracture mechanics parameters.

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