Accuracy Study of Stress Intensity Factor Solutions Obtained by Commercial FE Software

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Abstract. This paper deals with the problem of calculation of Stress Intensity Factor in two ways: theoretically and numerically with two methods: Virtual Crack Closure Technique and J – Integral method. Three types of geometries were considered: plates with central/boundary crack and notch bending specimen. Numerical simulations covered a mesh sensitivity study for three mesh sizes and linear/nonlinear material model. Good correlation between exact solution and numerical tests was achieved.

INTRODUCTION

Fracture mechanics is a field of science, which focus on initiation and extension of cracks in constructions, starting with civil engineering (concretes) up to aircraft industries (planes). It basis on the rules of solid mechanics, which are used to determine the stress distribution near the crack tip. Fracture mechanics may be examined in two ranges: for linear and nonlinear material behavior. The beginning of linear fracture mechanics goes back up to 1920, when Griffith [1] started considerations about damage and crack distribution on brittle materials, which formulated a criterion based on energy release rate. It was based on Inglis's [2] research, according to which the stress level approach infinity as the ellipse flattened to form a crack.

The most important parameter for fracture mechanics, which is used to determine the state of stress caused by the externally applied forces in the area near crack tip is Stress Intensity Factor (SIF). It usually refers to elastic materials and is used for prediction of failure criterions in brittle materials. This parameter is strongly dependent from geometry (shape and dimensions of sample) and loading conditions (value and way of loading).

The aim of this paper is comparison the effectiveness of Virtual Crack Closure Technique and J – Integral methods for SIF calculation in linear and nonlinear fracture mechanics with exact and simplified theoretical solution. Three different cases of crack geometry were compared. Mesh sensitivity study was performed and stress distribution through cross section through the plane of crack were compared. As a numerical solver MSC.Marc commercial code was implemented.

METHODOLOGY

As mentioned before Stress Intensity Factor has a crucial meaning in fracture mechanics. Calculation an exact solution is possible for simple geometries which are loaded in a steady way. For more complex shapes with many non-regular cracks it is necessary to use numerical methods which are basis on results from static analysis using Finite Element Analyses (FEM). The most commonly used computer method for SIF calculation methods:

- Virtual Crack Closure Technique (VCCT) – is based on energy release rate. The main assumption is that energy needed to separate the surfaces of crack is the same as the energy needed to close this surface. It considers three modes of cracking [3].

- J – Integral – a way to calculate strain energy release rate (work) per unit fracture surface area around a crack tip. Parameters calculated using this method for linear elastic and perfectly brittle material are directly related with fracture toughness [4].

MODELING AND RESULTS

Prepared models served to perform static linear and nonlinear analyses of chosen geometries with predefined crack tips. A material used in numerical simulation was steel, characterized by yield stress equal to 265 MPa. The load was determined to induce a plastic strain on the sample.

Results from performed simulations shown good correlation between theoretical and numerical solution. Simplified solution which is intended for geometries where length to width ratio is small given a significant error. Finally a big influence of mesh size was observed: maximum error occurred for the largest elements (2,5 mm) and was equal to 11.3 %, and decreased while dividing an elements. There is no significant difference between VCCT and J-integral method for linear and nonlinear material, but it was noticed that results obtained with VCCT fits better to theoretical values. Additional geometries: plate with central crack and simply supported beam witch notch placed on the center are presented on a full paper.

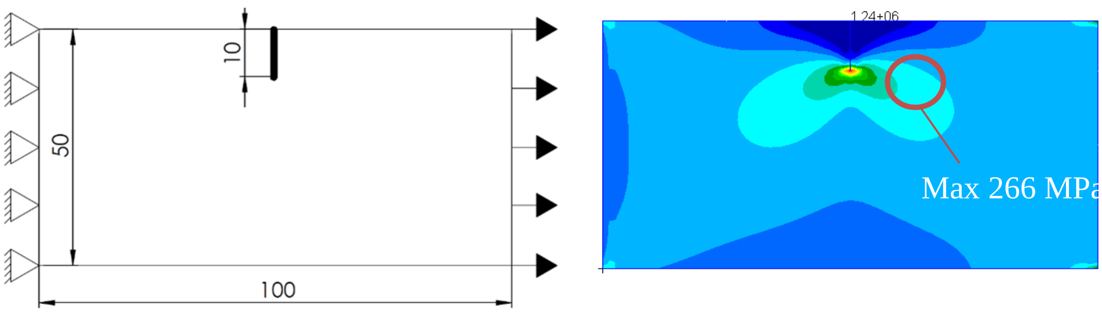

Figure 1. Scheme [mm] and stress distribution [MPa] of analyzed case

Method	0,625[mm]	1,25 [mm]	2,5 [mm]	Theory	Simplified theory
Linear material model					
J-Integral	984.4	942.9	897.6	1012.0	675.6
VCCT	1005.3	975.6	904.1		
Nonlinear material model					
J-Integral	987.1	949.4	907.5	1012.0	675.6
VCCT	1007.2	968.1	921.3		

Table. 1. Comparison of Stress Intensity Factor from numerical and theoretical solutions

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