

Versatile Analysis of Defects in 3D Solid based on Body Force Method

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Fatigue durability, damage tolerance and strength evaluations of cracked structural components require accurate determination of stress intensity factors (SIFs) of the cracks. SIF gives a measure of intensity of singular stress field in the crack tip region. Crack propagation is controlled by the stress field near its tip and the stress field is asymptotic dominant or singular. Not only the single crack but crack to crack interaction can change the stress distribution near the macro crack tip. Problems related to interactions of multiple cracks have wide applications in analysing damage mechanisms of brittle materials such as concrete, rocks and ceramics. Such an interaction is also important in assessing the integrity of interfaces in bonded structures. The study of interacting cracks subjected to a given set of external load is extremely important to design and safe life prediction of mechanical structures. Thus, the fracture behaviour of multi-cracked materials has become a key issue in fracture mechanics and recently has received large attention. SIF and stress concentration due to interaction between cavities and crack-cavity interaction in elastic solids play not only an important role in theoretical elasticity but also are recognized as a critical factor governing fatigue and fracture of materials. Also, the analysis of crack propagation as well as the life time prediction is very important and essential in engineering applications. There have been many numerical approaches proposed to calculate stress concentration, stress intensity factors and crack propagations. But in all cases, mathematical analysis and numerical program has been developed for each situation. In this research to calculate SIF, stress concentration and crack propagation the body force method (BFM) is used. The BFM has been provided highly accurate solutions of stress concentration factors and SIFs of practically important problems, but a versatile stress analysis program applicable to arbitrary shaped 3D cracks has not been developed until today.

The purpose of present study is to develop a fast and robust analysis environment to evaluate the stress distribution and SIF along 3D crack front of arbitrarily-shaped and oriented in an infinite solid under various loading. In this study, a stress calculation code based on the BFM has been developed, which is applicable to versatile analysis of 3D elastic body. The 3D crack and cavity problem is formulated in terms of singular integral equations with singularity of the

order of r^{-3} and r^{-2} for crack and cavity respectively, where r is the distance between source and reference points. The stress field induced by a body force and body force doublet in an infinite body is used as a fundamental solution. The unknown functions are approximated by the product of fundamental density and weighting function. To remove the singularity and to improve the accuracy of the numerical integral, a polar transformation scheme is introduced. Finally, the unknown distribution of the body force and body force doublet is solved by transforming the boundary integral equation into a set of simultaneous equations. In addition to the theoretical background of the present method, several numerical results are shown in tables and graphs.

By employing the developed program, practically important 3D crack problems are analysed. In the present method, the surface of the crack and cavity is modelled by number of small triangular elements. In order to assure the numerical accuracy of the SIF calculation, several problems such as rectangular, penny-shaped and elliptical cracks embedded in an infinite elastic body were examined. To validate the current analysis, the numerically obtained solutions were compared with available solutions in the literature. It was found that as the number of triangular elements increases, the estimated SIF and stress distribution converges gradually to the reference value. Even in the most coarse divisions of the crack, the obtained numerical solutions showed less than 1% relative error. In this study, not only a single crack problem but also multiple interacting cracks in an infinite solid were analysed to determine the stress field as well as SIFs along the crack front. The influences of crack to crack interference are analysed systematically by changing the number of cracks, distance, orientation and size of each crack. Numerical stress analyses are also examined by changing the radius of cavity and the distance between the cavity and the crack front systematically. Numerical results are presented for the stresses along the centreline between cavity and crack. The crack growth processes are also simulated numerically with an incremental crack-extension analysis based on the minimum strain energy density criterion and Paris law by using the present program. For each crack extension, the size of the increment of crack and direction of crack growth is evaluated along the crack front.

Accurate and fast evaluation of the SIFs and stress concentration for 3D cracks and cavity shows that the proposed procedure is simple and robust for SIF, stress distribution, stress concentration calculation and crack propagation analysis. It was ascertained that the present method is very user friendly and applicable to wide range of 3D arbitrary shaped and oriented crack-cavity problems for various practical applications.