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ЗМІСТ

CRACK INITIATION AND PROPAGATION IN STRUCTURAL ELEMENTS OF ENERGY MACHINERY

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Energy equipment such as hydro turbine casings, wind and steam turbine blades, and rotating shafts [1,2] is routinely exposed to periodic or short-term impulsive loads. Repeated action of these loads can initiate and propagate crack-like defects, ultimately reducing the durability and service life of structural components. Ensuring accurate predictions of fatigue resistance is therefore essential for the reliability and safety of such equipment.

The present study focuses on the problem of estimating the number of loading cycles to failure for structural elements that contain circular technological holes and are weakened by cracks. The structure is modeled under cyclic tension–compression loading with prescribed amplitude and frequency. To address this, a methodology is developed for evaluating the stress intensity factors in a structural element with two symmetric cracks emanating from the boundary of a hole.

The evaluation of stress intensity factors is formulated as the solution of a singular integral equation, which is numerically treated using the boundary element method. To improve computational efficiency, explicit formulas are derived for the accurate evaluation of singular integrals with Cauchy- and Hadamard-type singularities. The accuracy of numerical solutions is investigated for different density approximations of boundary elements, and it is established that cubic density functions yield significantly improved results compared to lower-order approximations. The unknown densities obtained from the integral equations are then employed to calculate stress intensity factors with high precision.

A comparison of analytical and numerical solutions to the singular equation confirms the validity of the proposed approach. Based on the threshold value of the stress intensity factor, the critical initial crack length marking the onset of crack growth is determined. Using Paris' law, the critical number of loading cycles required for the crack to reach an unacceptable size is calculated, providing a quantitative durability characteristic.

For benchmarking, the critical number of cycles is also evaluated for plates with single isolated cracks and for plates containing chains of cracks. The results demonstrate that, under identical loading conditions, the lowest durability corresponds to structural elements with cracks located in close proximity to technological holes. This finding underscores the necessity of considering stress concentrators in fatigue life assessments and highlights the sensitivity of structural durability to initial defect location and geometry [3].

Numerical modeling of stress concentration in bodies with circular cracks was performed using the boundary element method (BEM) and the finite element method (FEM). For comparison, analytical solutions of hypersingular integral equations were also employed. The results indicate that the one-dimensional hypersingular equation provides high accuracy, allowing the stress intensity factor to be computed with minimal error. However, the applicability of this approach is limited by the geometry of the problem (circular and elliptical domains). The two-dimensional hypersingular equation offers slightly lower accuracy but is considerably more versatile. The finite element method also yields good results, although it requires significantly greater computational resources [4]. Calculations of the number of cycles to failure of a fuel tank with a crack have been carried out. The results indicate that the presence and location of cracks relative to stress concentrators, such as holes, significantly reduce the durability of structural components. Specifically, elements with cracks adjacent to holes exhibit the lowest number of cycles to failure under identical loading conditions. The methodology also enables quantitative predictions of critical crack lengths and the number of loading cycles to failure using Paris' law, providing valuable guidance for fatigue assessment and design optimization.

Finally, the combined use of BEM, FEM, and analytical solutions offers a comprehensive framework for analyzing crack propagation in engineering structures, balancing computational efficiency, accuracy, and versatility. The findings are particularly relevant for components of energy equipment, such as fuel tanks [5], turbine blades, and rotating shafts, where cyclic or impulsive loads are prevalent.

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