CRACK PROPAGATION IN TWO-BELT BEAMS

S. V. Shkaraev, B. A. Sergeev, and S. D. Poznyshev

Problems of the effect of reinforcing elements on failure of tensile loaded panels have been examined in great detail. A number of calculations were carried out to determine the stress intensity factor (SIF) in separation $K_I$ by both analytical [1-3] and numerical methods [4, 5]. Calculations were carried out for the panels of different geometry with different positions of cracks in them. It was thus possible to propose recommendation for designing panels with extended life in practice. Biaxial tensile loading of panels has been examined [5]. All these studies and the majority of others were concerned with analysis of separation cracks.

Previously [6], the method of finite elements and a program [7] were used to determine the SIF in separation $K_I$ and transverse shear $K_{II}$ for a symmetric crack situated below a central stringer. The panel was loaded in tension and shear. Analysis shows that the stringers do not cause any appreciable reduction of $K_{II}$. This stresses that it is important to examine standard structural elements with cracks working under conditions of combined loading.

These elements include two-belt beams subjected to cyclic loading by transverse forces. The thin web reinforced with transverse flanges receives flows of tangential forces, whereas the belts are subjected to normal forces caused by bending. Experiments and service experience show that the webs contain rapidly propagating cracks whose propagation mechanism requires examination.

In this work, the finite element method is used to analyze the formation and nature of propagation of cracks in the web of a beam.

Formulation of the Problem

The web and the belt of the beam (Fig. 1) were made of aluminum alloy with an elasticity modulus of 66 GPa, and a Poisson's coefficient of 0.3. The web thickness was 3 mm. The belt thickness 35 mm and its width $b_B$ varied within the limits of the calculation zone (see Fig. 1) from 132 to 143 mm. The longitudinal joint between the belt and the web was ensured by titanium bolts 6 mm in diameter. The beam was subjected to cantilever loading with a transverse force with $P = 110$ kN.

In the experiments the cracks form at the edge of holes for bolts at angles $\alpha$ to the axis of the beam of 0 and 180° (type D crack, Fig. 2), 45° (type A), 90° (type C). In cyclic loading these cracks propagate mainly in the straight direction with greatly differing speeds. The mechanism of formation and propagation of cracks was analyzed by the finite element method (FEM) applied using a modified program [7].

The structures simulated by 12-node isoparametric elements (Fig. 3a). The joint between the web and the belts and the flanges was produced using one-dimensional finite elements whose rigidity was determined by empirical equations [8]. The initial grid consisted of 298 flat and 124 one-dimensional elements. Calculations were carried out using the FEM and the beam theory. The maximum difference in the tangential stresses in the web was 5% and of the normal stresses in the belt 10%.

To examine the interaction of the bolt with a hole, it is necessary to simulate this zone in great detail. This type of simulation is also required for evaluating the SIF at the tips of cracks of different types and length. In the FEM an increase of the density of the grid in the local region does not change the remaining part of the model. It is therefore convenient to use an algorithm of superelement calculations placing in the superelement the entire structure, with the exception of this zone (Fig. 3b). Fragments 1-4 in Fig. 4 of the

Fig. 1. Design of a two-belt beam.

Fig. 2. Types of fatigue cracks in the web.

Fig. 3. Finite element discretization of the calculation zone (a) and part of the web in the zone of the longitudinal joint (b).

finite-element grid represent the zone of the web in the region of its longitudinal contact with the belt.

Analysis of the contact interaction of the bolt and the fastening hole in the web was carried out using an iteration algorithm assuming there is no friction between them. The center of a disk simulating the bolt is connected with the corresponding node of the belt by means of a one-dimensional finite element (fragment 2 in Fig. 3b). The tip of the crack is surrounded by singular finite elements. The four functions of these elements is played by term which reflects the singularity of displacement at the tip. Crack length \( L \) was varied from 15 to 40 mm by deforming the grid. Short cracks up to 15-mm long were examined on grids (fragment 2 in Fig. 3b) which included the fastening hole. Fragments 3 and 4 were used for longer cracks.