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Technical Note

Determination of stress intensity factors for cracked bridge roller bearings using finite element analyses

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ABSTRACT

In this work, the finite element method is employed to gain an understanding of the behaviour of a cracked bridge roller bearing in service. The cracked roller is considered as a two-dimensional edge-cracked disk subjected to a radial compressive line load. The crack parameters K_I and K_{II} are calculated for the relevant load configuration and angle of disk rotation. The calculated data are also used to check the accuracy of approximate SIF solutions reported earlier (Schindler, 1990; Schindler and Morf, 1994). For plain Mode I loading very good agreement is found between the obtained results and data presented in Schindler and Morf (1994).

1. Introduction

In recent years several large cracks were detected and some sudden failures occurred in Swedish bridge roller bearings made of martensitic stainless steel. Rollers may crack after only a few years in service thus giving rise to serious maintenance problems, often involving complicated jacking procedures in bearing replacement work. Typically, cracking starts at a roller end face just beyond the compressive contact zone and extends in a radial plane [3].

The rollers were designed in the 70s or earlier according to the Hertz solution of the contact problem rigid cylinder and elastic half-space. The behaviour of the cracks observed appears to be somewhat unusual, in that initiation occurs in a region of tensile stress beyond the contact surface [3] and the nominally compressive stresses in the Hertzian contact region do not exceed certain maximum allowable values as defined in pertinent regulations [5].

Perhaps the best approach towards an explanation of fractures observed in practice is that by Schindler [1,2] introducing the idea of a swinging Hertzian stress-field: due to daily and seasonal thermal deformation of a bridge girder (superstructure), a radial crack rotates around a mean position under predominantly Mode II loading.

Stress intensity factors (SIF) for an edge-cracked disk subjected to crack surface loading have been obtained by several authors using the weight function method and ad hoc manipulations [6–9], while solutions for compressive radial loading, which occurs in practice, have not been found in the literature. However, none of the weight function method solutions appear to give satisfactory results for the cracked roller.

Considering the resultant of compressive stresses acting on a disk as a point load on one side of the crack-mouth in an edge-cracked disk, Schindler presented approximate closed form solutions for the Mode I SIF using the principle of superposition [1,2]. The K_I solution by Schindler in [1] has been re-derived by the authors and the results are compared.

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For K_{II}, Schindler [1,2] suggested the SIF of an edge crack in a strip of width 2R, where R is disk radius, Fig. 1, loaded by two coplanar opposite forces acting on each side of the crack-mouth [10].

In the present work, linear elastic fracture mechanics finite element analyses (FEA) are performed in order to compute the SIFs K_I and K_{II} of the cracked roller for the relevant load configuration and degree of rotations. The results are also compared with approximate solutions reported by Schindler [1,2] to check the agreement of the numerical solutions.

2. Analytical solutions

Schindler [1,2] considered the resultant of the compressive stresses, σ_c, as a point-load P acting on one side of the crack-mouth (system A) for cracks of length $a \gg e/2$ and $a \gg s$, where e and s are shown in Fig. 1(a). He decomposed this load configuration using the superposition principle into the systems B and C, Fig. 1(b).

He assumed that the system B crack behaves approximately like an edge crack in a strip of width 2R, loaded by two coplanar opposite forces acting on each side of the crack-mouth, according to Tada et al. [10].

$$K_{II} = \frac{P}{\sqrt{D}} \frac{\left(1.30 - 0.65A + 0.37A^2 + 0.28A^3\right)}{\sqrt{\pi \cdot A(1-A)}} \tag{1}$$

where $A = \frac{a}{2R}$

In the symmetric system C, the crack-mouth region subjected to the two point-loads deforms elastically, closes the crack, and a horizontal contact force Q develops. The magnitude of Q can be calculated from the displacement d of a crack edge free to move across the symmetry-axis and the compliance of the crack-mouth region. For cracks $a \leqslant R$, the displacement d can be calculated approximately by modelling a triangular region between a crack surface and the outer surface of the disk as a clamped cantilever beam, here OAA', with linearly increasing cross-section, Fig. 2.

Assuming the x–axis as the centreline of the cantilever beam, which is assumed rigidly attached to the reminder of the specimen along the line AA', the bending moment acting on the beam cross-section BB' is given

$$M(x) = T \cdot x \tag{2}$$

The height of this beam cross-section, given by the line BB' is 2x. According to elementary beam theory the deformation energy per unit length of a beam is given by:

$$\frac{dU}{dx} = \frac{M^2}{2EI} \tag{3}$$

where $I = bh^3/12$, in which b is taken as unit and $h = 2x$.

The deformation energy of the beam per unit thickness is given by

$$U = \int_0^l \frac{M(x)^2}{2EI} dx = \frac{1}{2E} \int_0^l \frac{(T \cdot x)^2}{(2x)^3/12} dx = \frac{3T^2}{4E} \int_0^l \frac{dx}{x} \tag{4}$$

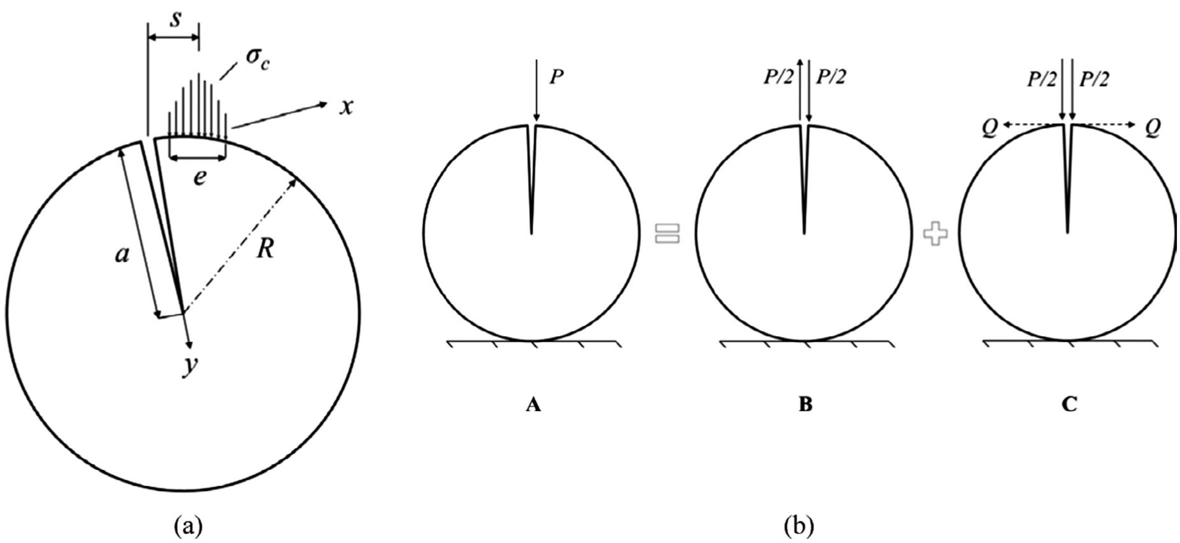

Fig. 1. Schematic sketch of: (a) the crack load and (b) decomposition of the load.