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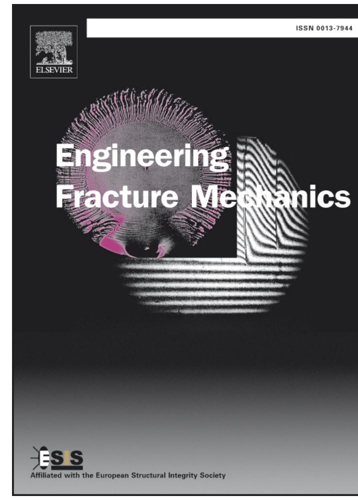

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Stress intensity factors for axial semi-elliptical surface cracks and embedded elliptical cracks at longitudinal butt welded joints of steel-lined pressure tunnels and shafts considering weld shape

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Abstract

When for steel liners of pressure tunnels and shafts high-strength steels are used, welded joints are subject to the risk of hydrogen induced cold-cracking in the base material. Longitudinal butt welded joints are critical regions as they are loaded transversely. For an accurate engineering fatigue and fracture assessment, solutions for stress intensity factors (SIF) are required, considering the weld shape and the global behavior of the liner (i.e., geometrical imperfections and interaction with surrounding concrete and rock). In this study, SIF for axial semi-elliptical surface cracks and embedded elliptical cracks at longitudinal butt welded joints of steel liners are studied by means of the finite element method. At first the applicability of published parametric equations for SIF of elliptical cracks in plates is validated. Then the influence of the weld shape is assessed through a systematic parametric study. It is shown that the weld profile has a significant influence on SIF for semi-elliptical surface cracks while it has no significant influence on SIF for embedded elliptical cracks within the studied range of relative crack depth. Finally, a new parametric equation is proposed to estimate the weld shape correction factor for semi-elliptical surface cracks.

Keywords: Steel liners, Stress intensity factors, Embedded cracks, Surface cracks, Finite element analysis

1. Introduction

Steel-lined pressure tunnels and shafts (SLPT&S) of hydroelectric power plants (HPP) are multilayer (see Fig. 1) civil engineering structures with a high potential of damage since a failure of the lining could induce catastrophic hydraulic jacking, particularly for high-head HPP [1]. SLPT&S are subject to harsher transients water pressures as the energy demand keeps increasing, the energy market is liberalized and new volatile renewable energies are integrated into the grid [2]. This increased number of loading cycles raises the issue of fatigue for these welded steel structures. Pumped-storage HPP are particularly sensitive to these new operational conditions, as they are used to balance the electricity grid on an intra-daily time scale.

To address the high mechanical performance requirements, high-strength steels (HSS) are used and allow the design of thinner and thus more economic liners. However, it is often stated in the literature that welded HSS do not provide higher fatigue resistance than lower steel grades [3–7]. Welded HSS are also subject to the risk of hydrogen induced cold-cracking (HICC) [8–17]. In the late 1950s when the application of quenched and tempered (Q+T) fine grain steels was initiated, HICC issue occurred in the heat-affected zone (HAZ) [9, 11]. With the development of grades S690 and S890 Q+T, the risk of HICC was shifted from the HAZ to the weld deposit [9, 11].

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