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Collapse load for a crack in a plate with a mismatched welded joint

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Abstract

The accuracy of flaw assessment techniques for welded joints is directly related to the accurate estimate of the yield collapse load. A careful finite element limit analysis can provide a very good and reliable assessment of the collapse load. Unfortunately, such an analysis is normally time-consuming and requires a substantial effort in order to validate the finite element calculations. In this paper we apply the classical upper bound theorem of plasticity to develop simplified solutions for a through crack in a tensile plate with a mismatched welded joint. The weld configuration is idealised as a simple sandwich model and the collapse load is derived analytically from a solution of an extreme-value problem. The theoretical solutions are then verified by independent finite element calculations. The proposed solutions seem to be very effective and accurate and can be easily generalized for many other weld geometries and loading conditions.

Keywords: Plastic collapse; Elastic–plastic material; Welds; Fracture in plates

1. Introduction

Situations when the weld metal and base material have different values of yield stress are very common for many engineering structures such as bridges, ships, piping and pressure vessels. The accurate estimation of collapse loads is essential for assessing the integrity of cracked structures with welds. A wide range of techniques has been used in the past to provide sufficiently accurate values for the limit (or collapse) load. Based on slip line field (SLF) analysis, Hao et al. [1] obtained a yield load solution for mismatched middle

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Nomenclature

a	half length of a centre crack
B	plate thickness
e	crack eccentricity
F	applied force
F_B	net section collapse load
F_M	collapse load for mismatch configuration
H	half width of weld metal strip
M	mismatch factor defined for yield strength ($M = \sigma_{YW}/\sigma_{YB}$)
W	(half) width of plate
ε	normalized crack eccentricity e/H
σ_Y	yield strength, general
σ_{YB}	yield strength for base material
σ_{YW}	yield strength for weld material
Ψ	normalised remaining ligament $(W - a)/H$
χ	geometry factor of the weld joint $\chi = a/W$
τ_{YW}	yield stress of the weld material in shear
τ_{YB}	yield stress of the base material in shear

crack tension $M(T)$ plates. Based on the assumed deformation fields proposed by Joch et al. [2], Hornet and Eripret [3] proposed an approximate solution for mismatched $M(T)$ and single edge cracked bend plates. Kim and Schwalbe [4] conducted a comprehensive review of these techniques and concluded that although time and cost consuming, the finite element (FE) analysis based on elastic-perfectly plastic material model is currently the most effective and reliable approach to the calculation of the limit load in defective mismatched structures.

The main objective of the present paper is to develop an effective yet simple analytical approach for the assessment of the collapse load for plates with cracks in mismatched welds using the classical upper bound theorem of plasticity. Hornet and Eripret [3] have used this theorem before for mismatched welded structures by invoking simple assumed deformation fields. Unfortunately, the previous application of the upper bound theorem of plasticity led to unacceptably higher values than the actual collapse load for highly under-matched plates [4]. The current approach is different from what has been done before and reduces the problem under consideration to an extreme-value problem for which the limit load is derived analytically. As it will be shown later in this paper it provides a very effective way to analyse cracked structures with mismatched weldments and with some physical insight, the approach can be used to get a very accurate assessment of the collapse load with very little effort. It will be demonstrated that the proposed method overcomes problems with highly under-matches plates and agrees well with independent FE studies. It can be easily generalized for many other practically important cases of mismatched welded structures.

2. Deformation patterns

An actual weld joint is very complicated, both on micro- and macro-levels. In practical situations, the welding process affects material properties in the heat-affected zone (HAZ). The presence of residual stresses makes the situation further complicated, rendering analytical solutions nearly impossible [5]. For this