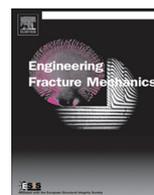




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Mode I stress intensity factor for cracked thin-walled open beams



Víctor H. Cortínez*, Franco E. Dotti

Centro de Investigación en Mecánica Teórica y Aplicada, Facultad Regional Bahía Blanca, Universidad Tecnológica Nacional, 11 de Abril 461, B8000LMI Bahía Blanca, Argentina
Consejo Nacional de Investigaciones Científicas y Técnicas, Av. Rivadavia 1917, C1033AAJ Ciudad Autónoma de Buenos Aires, Argentina

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ABSTRACT

A general analytical method to determine the mode I stress intensity factor for thin-walled beams is presented. This method is based on the concept of crack surface widening energy release rate, which is expressed in terms of the G^* integral and the thin-walled beam theory. A distinctive aspect of this technique is the incorporation of the warping effect, which is a common feature in thin-walled beams that significantly influences in the stress distribution. This characteristic gives generality to the method, allowing the analysis of crack scenarios that have not been yet considered by other authors. The results show a good agreement with shell finite element solutions and other results available in the literature.

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1. Introduction

Thin-walled beams are widely employed in modern engineering structures. For this reason, the study of crack behavior in these structural components represents a topic of crucial importance. The mode I stress intensity factor is a very significant parameter in the integrity evaluation and risk analysis of structures. The determination of an exact solution for the stress intensity factor is usually a difficult enterprise. In thin-walled beams, the presence of sectional warping constitutes an additional problem. Although some approaches have recently been proposed in this direction [1–3], no one have regarded flexural–torsional loads, which activate the warping effect.

The purpose of this article is to present a technique to determine the mode I stress intensity factor for cracked thin-walled beams. This technique is based on the G^* integral concept and the thin-walled beam theory. G^* integral [4] is derived from the conservation law and the concept of crack mouth widening energy release rate. It has shown to be easy to employ in the determination of closed forms for the stress intensity factors in several crack problems [1,2,5]. Thin-walled open beam theory [6–8] considers the warping effect derived from the natural flexural–torsional coupling of this kind of structures. In the determination of mode I stress intensity factor, warping is taken into account by considering the energetic contribution of the bimoment force.

* Corresponding author at: Centro de Investigación en Mecánica Teórica y Aplicada, Facultad Regional Bahía Blanca, Universidad Tecnológica Nacional, 11 de Abril 461, B8000LMI Bahía Blanca, Argentina. Tel.: +54 291 4555220; fax: +54 291 4555311.

E-mail addresses: vcortine@frbb.utn.edu.ar (V.H. Cortínez), fdotti@frbb.utn.edu.ar (F.E. Dotti).

Nomenclature

a	crack depth (also semi-major axis of the elliptic crack)
\bar{a}	boundary of the elliptic crack
A	cross-sectional area
b	dimension of a flange
B	bimomental beam force (also point B , origin of the system $B: x, s, n$)
c	semi-minor axis of the elliptic crack
C	center of gravity of the uncracked cross section
C_{ij}	element of order (i, j) of the inverse of the constitutive matrix
C_w	warping constant
C^*	crack mouth widening energy release rate
\mathbf{G}_c	vector containing elements of the inverse of the constitutive matrix
h	dimension of the web
\mathbf{I}_i	identity matrix of size i
I_y, I_z	second moments of area
I_{yz}	product moment of area
$I_{y\omega}, I_{z\omega}$	product of warping
\mathbf{J}	constitutive matrix
K_I	mode I stress intensity factor
L	length of the beam
n	coordinate normal to the cross-section middle line
N	axial beam force
M_y, M_z	bending moments
\mathbf{Q}	vector of generalized forces
\mathbf{Q}_c	vector containing squares and products of the generalized forces
r	radial coordinate
s	circumferential coordinate
S	cross-sectional perimeter
S_y, S_z	first moments of area
S_{ω}	first moment of warping
t	beam thickness
\mathbf{T}	stress vector
T_x, T_s	elements of the stress vector
u	axial displacement
\mathbf{u}	displacement vector
U	strain energy
U_0	strain energy density
v	circumferential displacement
x, y, z	Cartesian coordinates
Y, Z	coordinates of a point located in the middle line of the cross-section
α_i	coefficients of the axial stress in cracked cross-section
γ	vector of shape functions associated to cracked cross-section
Γ	integration path
Δ	vector of generalized strains
η_x, η_s	components of the unit outward normal vector
θ	angular coordinate
θ_x	warping variable
θ_y, θ_z	bending twists
λ	auxiliary integration variable
ν	Poisson's ratio
ξ	crack location (axial coordinate)
Π	total potential energy
σ_{xx}	axial stress
ω_p	primary warping function
$(\cdot)^{(0)}$	superscript associated to the uncracked cross-section
$(\cdot)^{(c)}$	superscript associated to the cracked cross-section
$(\cdot)^{(R)}$	superscript associated to the cracked flange or web of the beam

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