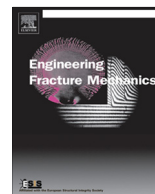




ELSEVIER

Contents lists available at ScienceDirect

## Engineering Fracture Mechanics

journal homepage: [www.elsevier.com/locate/engfracmech](http://www.elsevier.com/locate/engfracmech)

# General cracked-hinge model for simulation of low-cycle damage in cemented beams on soil

Asmus Skar<sup>a,\*</sup>, Peter Noe Poulsen<sup>b</sup>, John Forbes Olesen<sup>b</sup><sup>a</sup>COWI A/S, Parallevej 2, 2800 Kgs. Lyngby, Denmark<sup>b</sup>Technical University of Denmark, Brovej, Building 118, 2800 Kgs. Lyngby, Denmark

## ARTICLE INFO

*Article history:*

Received 2 September 2016

Received in revised form 11 January 2017

Accepted 16 January 2017

Available online xxxx

*Keywords:*

Fracture mechanics

Cohesive crack

Non-linear FEM

Low-cyclic fatigue

Cemented materials

Pavement analysis

## ABSTRACT

The need for mechanistic constitutive models to evaluate the complex interaction between concrete crack propagation, geometry and soil foundation in concrete- and composite pavement systems has been recognized. Several models developed are either too complex or designed to solve relatively simple problems, e.g. limited to one type of load configuration or test set-up. In order to develop a general and mechanistic modeling framework for non-linear analysis of low-cycle damage in cemented materials, this paper presents a cracked-hinge model aimed at the analysis of the bending fracture of the cemented material. The model is based on the fracture mechanics concepts of the fictitious crack model. The proposed hinge is described in a general and consistent format, allowing for any type of stress-crack opening relationship and unloading- reloading formulation. The functionality of the proposed hinge model is compared to numerical- and experimental results. The proposed hinge shows good performance and seems promising for the description of low-cycle fracture behavior in cemented materials.

© 2017 Elsevier Ltd. All rights reserved.

## 1. Introduction

Concrete- and composite pavement systems are subjected to cyclic loading from vehicles resulting in initiation of bending cracks in the quasi-brittle cemented material. Subsequently, these cracks propagate leading to failure of the pavement structure. The structural design of such pavements is primarily based on empirical formulas which convert the elastic response analysis into a measure of performance [1–3], referred to as the Mechanistic-Empirical (M-E) method. However, such a method cannot account for significant factors influencing the response, e.g. describing the interaction between loads, material properties, geometry and soil foundation in a unified manner.

The limitations of the M-E method and the growth in computer capabilities have resulted in an increasing development of more rational models for pavement analysis during the past decades. That work began in the early 1990s, studying mainly asphalt concrete mixtures in flexible pavements [4–6], reflective cracking in asphalt overlays [7] and permanent deformation of unbound materials [8–10]. These models are typically based on a mechanistic approach using appropriate numerical tools, e.g. the finite element (FE) method. This allows for geometry, inhomogeneities, anisotropy, and nonlinear material properties of all pavement layers to be considered.

Numerical analysis of crack propagation in concrete- and composite pavement systems have primarily carried out applying cohesive zone modeling [11–15]. Gaedicke and Roesler [16,17] applied a cohesive zone model for studying fracture in

\* Corresponding author.

E-mail address: [asch@cowi.dk](mailto:asch@cowi.dk) (A. Skar).

**Nomenclature**

$a_i$	slope of tangent line segment on softening curve
$a_0$	depth of notch
$b_i$	intersection of the tangent line segment on softening curve and the abscissa
<b>B</b>	strain interpolation matrix
$c_1$	softening curve model parameters
$c_2$	softening curve model parameters
<i>CMOD</i>	measured crack mouth opening displacement
<i>cp</i>	constitutive point
$c$	crack-length
$d$	distance from beam face to measurement point
<b>D<sub>t</sub></b>	hinge tangent stiffness matrix
$e_i$	lever arm of hinge fiber
$E_c$	Young's modulus of cemented material
$E_d$	damaged unloading- reloading stiffness of hinge fiber
$f_t$	uni-axial tensile strength of cemented material
$G_F$	fracture energy
$h$	hinge height
$H$	beam height
$ip$	interpolation point
$k_1$	softening curve model parameters
$k_h$	horizontal spring stiffness
<b>k<sub>t</sub></b>	beam element tangent stiffness matrix
$k_v$	vertical spring stiffness
$L$	beam length
$L_e$	beam element length
$M$	moment force
$N$	normal force
<b>N</b>	displacement interpolation matrix
$n$	number of fibers
$P$	load
<b>q</b>	beam element internal nodal force
$s$	hinge width
$t$	hinge thickness
$u$	elongation of hinge fiber
<b>v</b>	element dof vector
$w$	crack-opening
$w_c$	zero-stress displacement
$w_{k_1}$	softening curve model parameters
$\alpha_i$	monotonic damage parameter
$\delta$	total midspan displacement of beam
$\delta^{cr}$	cracking beam midspan deformation of hinge
$\delta_g$	geometrical amplification
$\delta^{el}$	elastic beam midspan deformation of hinge
$\delta_e$	elastic deformation of specimen
$\delta_{COD}$	the opening due to the presence of the crack
$\bar{\epsilon}_0$	mean normal strain at beam axis
$\bar{\epsilon}$	mean normal strain of hinge fiber
$\epsilon_{ct}$	strain at crack initiation
$\bar{\epsilon}^{pl}$	mean plastic strain component
$\bar{\epsilon}^{cr}$	inelastic cracking strain component
$\eta$	tensile cyclic damage parameter
$\bar{\epsilon}_{ult}$	zero-stress strain
$\bar{\epsilon}^{uml}$	strain during unloading- and reloading
$\gamma$	shear coupling spring coefficient
$\bar{\kappa}$	mean curvature of the hinge
$\mu$	normalized moment
$\sigma_u^k$	negative intersecting point on abscissa
$\sigma_{ur}$	normal cohesive stress during unloading- and reloading of hinge fiber

Download English Version:

<https://daneshyari.com/en/article/5014007>

Download Persian Version:

<https://daneshyari.com/article/5014007>

[Daneshyari.com](https://daneshyari.com)