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Thin shell and surface crack finite elements for simulation of combined failure modes

B. Skallerud [a,*], K. Holthe [a], B. Haugen [b]

[a] Department of Structural Engineering, The Norwegian University of Science and Technology, N-7491, Trondheim, Norway
[b] FEDEM Technology a.s., Boulder, USA

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This paper is dedicated to Professor K. Bell on the occasion of his 65th anniversary

Abstract

In this study we present a new approach to analyse cracked shell structures subjected to large geometric changes. It is based on a combination of a rectangular assumed natural deviatoric strain thin shell finite element and an improved linespring finite element. Plasticity is accounted for using stress resultants. A power law hardening model is used for shell and linespring material. A co-rotational formulation is employed to represent nonlinear geometry effects. With this, one can carry out nonlinear fracture mechanics assessments in structures that show instabilities due buckling (local/global), ovalisation and large rigid body motion. By numerical examples it is shown how geometric instabilities and fracture compete as governing failure mode.
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Keywords: Plasticity; Large rotations; Co-rotated formulation; Assumed strain thin shell finite element; Linespring finite element; Nonlinear fracture mechanics

1. Introduction

Surface cracked shell structures occur in many industrial applications, e.g. pressure vessels, pipelines, tubular frame structures. Two main facts cause the occurrence of defects: the shell segments that the structure are fabricated from are usually joined with welds, and most structures are subjected some cyclic loading that promote fatigue crack growth. Although welding procedures have improved significantly over the

* Corresponding author. Tel.: +47 73 59 35 60; fax: +47 73 59 34 91.
E-mail addresses: bjorn.skallerud@ntnu.no, bjorn.skallerud@mtf.ntnu.no (B. Skallerud).

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years, some initial defects have to be expected and accounted for. In some applications the structure is subjected to very high loads. Traditional design rules for defect assessment often state that no defect can be accepted at all under loading conditions causing significant inelasticity. Hence, more advanced numerical assessment is the only way out of this dilemma. Traditionally, three-dimensional solid finite elements are employed in discretising the shell structure in order to account for the crack. Fig. 1 illustrates a typical mesh. This puts high demands on both pre- and post-processing in addition to long cpu times. An alternative is to use shell finite elements. Then the challenge is to account for the crack. This may be done using line spring finite elements at the crack location. Fig. 1 also illustrate such a mesh. For the meshes shown, a typical solid finite element mesh will have some 30,000 degrees of freedom (utilising two symmetry planes), whereas the shell model will have some 1000 DOF (using symmetry). A factor of 10 in reduced cpu is typical. But the main benefit of using shell/linespring elements is the reduced time spent in pre- and post-processing. Using linesprings, the crack is modelled as nonlinear springs between the shell elements, with a varying compliance as a function of crack depth and plastic deformations. The accuracy of the predicted fracture mechanics quantities such as crack tip opening displacement (CTOD) and J-integral is crucial for such an approach. The linespring element has a long history [1–4], and is implemented in some commercial codes. However, some limitations still exist, e.g. how to treat short cracks and large deformations. Short cracks are the most relevant in practical situations, that is cracks of depths less than about 25% of the shell thickness. In many applications there also is a need to account for large displacements and rotations, and simultaneously assess the criticality of the defect. In the present study these aspects are accounted for and implemented in a new commercial code denoted LINK. It is a general nonlinear shell finite element program accounting for large rigid body motion and plasticity. The shell element is a rectangular ANDES element in a co-rotated formulation [5,6]. The local strains are assumed small. Within this formulation an improved linespring finite element is implemented. Some background of the present linespring formulation is given in [7]. With this, one has a tool that can account for cracks and global/local buckling in the same simulation. One important industrial case where this is relevant is in laying of pipelines by means of reeling, with nominal strains that reach about 2% (both in tension and compression).

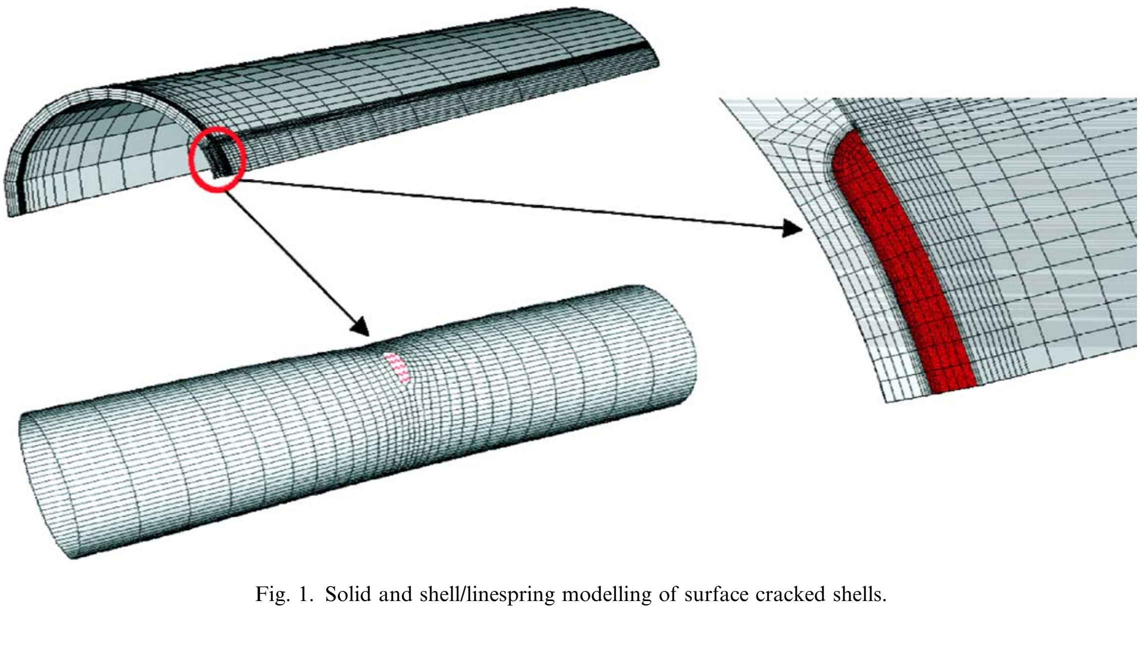

Fig. 1. Solid and shell/linespring modelling of surface cracked shells.

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