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An efficient approach for crack propagation analysis in shell structures

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1. Introduction

The crack propagation analysis in shell structures is very important to guarantee the safety of structures under various loadings. Due to the combination of in-plane and out-of-plane loadings, the analysis of cracked shell structures is more complicated than continuum problems. In addition, a difficulty in the simulation of crack propagation is the requirement of spatially conforming mesh for the changing topology of the domain. In this study, we employ the interface shell elements [1] with full consideration of transverse shear and membrane locking phenomena to place a local spider-web mesh centered at the crack tip in a global background mesh. With the great aid of interface shell elements, non-matching interfaces between the local and global meshes can be effectively connected. Moreover, the interface shell elements are also used for the trimmed shell elements created by cutting the background mesh with a crack line. When a crack propagates through the background mesh, the cracked shell model should be re-designed to accommodate a new topology due to the movement of the crack tip. We assume that the crack is moved by a small length increment at each step of crack extension when a crack propagation criterion is fulfilled.

2. The cracked shell finite element model

Let us consider a three-dimensional geometric surface discretized into quadrilateral shell elements for the global background mesh, as illustrated in Fig. 1. At the crack tip, a local spider-web mesh is created and projected onto the geometric surface due to the curvature with an arbitrary level of refinements. The interface shell elements are then employed for the trimmed shell elements along the crack line and at the non-matching interfaces between the background and spider-web meshes, as shown in Fig. 1. The present procedure provides a simple and efficient modeling approach to simulate crack propagation in shell structures. In particular, the well-shaped shell elements near the crack tip and in the global domain are maintained due to the advantages related to the use of interface shell elements.

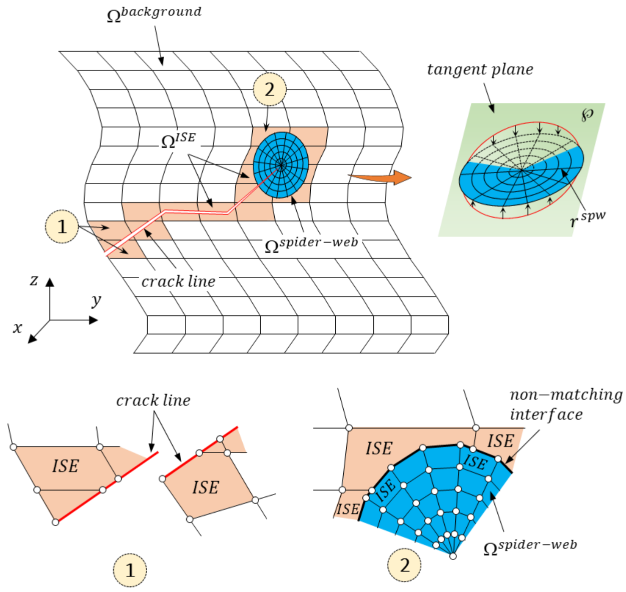

Fig.1 Construction of a cracked shell model with an arbitrary crack line.

3. The crack propagation criterion

In this study, the maximum circumferential stress criterion [2] is used to predict the crack growth angle as

$$\theta_c = \begin{cases} 2\arctan\frac{1}{4}\left(\frac{K_I}{K_{II}} + \sqrt{\left(\frac{K_I}{K_{II}}\right)^2 + 8}\right) & if\ K_{II} < 0 \\ 0 & if\ K_{II} = 0 \\ 2\arctan\frac{1}{4}\left(\frac{K_I}{K_{II}} - \sqrt{\left(\frac{K_I}{K_{II}}\right)^2 + 8}\right) & if\ K_{II} < 0 \end{cases} \quad (1)$$

Note that the crack front is assumed to be straight and aligned with the normal direction to the shell mid-surface.

4. Numerical results

An inclined cracked cylindrical shell is considered for crack propagation analysis. The geometry and boundary conditions are described in Fig. 2. The crack growth process is performed using 20 equal load steps with constant crack increment. Fig. 3 illustrates the steps 10, 15 and 20 of the cracked evolutionary with the distribution of displacements in z-direction. The good results are observed with all steps of crack propagation analysis.

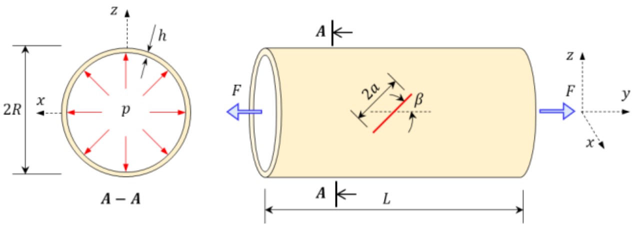

Fig.2 Geometry and boundary conditions of the inclined cracked cylindrical shell.

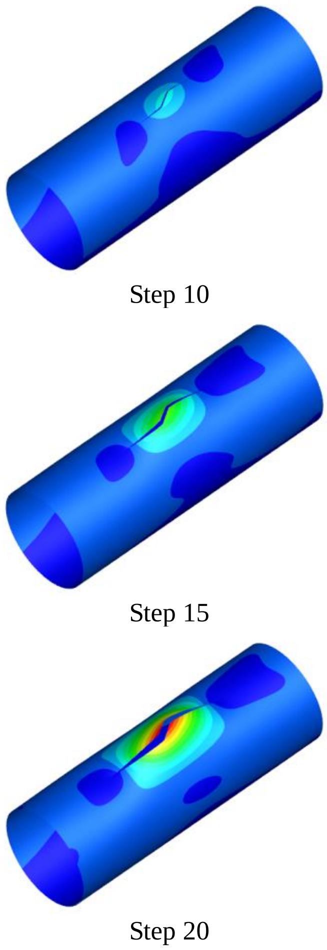

Fig.3 Deformation and distribution of displacement in z-direction of the inclined cracked cylindrical shell.

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