A NEW GENERATION OF BOUNDARY ELEMENT METHOD FOR DAMAGE TOLERANCE ASSESSMENT OF AEROSTRUCTURES

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ABSTRACT

This paper describes the considerable progress made in recent years in the development of boundary element technology for modelling and simulation of fracture and damage behaviour in complex structural parts. The analyses that include geometric and materials nonlinearities are robust companion to the established finite element method. Recent advances in modelling cracks in thin walled plates and shells are a clear and distinct progress in damage tolerance analysis for aerostructures.

1. INTRODUCTION

In order to ensure a reasonable cost for the design and maintenance of aircraft structures, it is generally accepted that computational analysis and simulation must partially replace full scale and laboratory testing. This is the case not only for designing new parts but also in maintaining aging structures. In any method for lifetime prediction of flawed structures, the effect of the geometry of components, or structures, and its interaction with the growing crack must be considered.
A new generation of boundary element formulations known as the Dual Boundary Element Method was developed by Aliabadi and his students [1-3] for modelling crack growth in two- and three-dimensional linear elastic problems. The formulation was subsequently extended to nonlinear and transient problems [4-13]. More recently, a new generation of boundary element method has been developed which allows for the application of the BEM to thin walled structures. The extension of the dual boundary element method to thin-walled problems has provided for the first time a comprehensive modelling tool using BEM.

In this paper application of the BEM to linear and nonlinear problems are reviewed. Here attention is paid to the application of the method rather than the detailed formulation. Readers interested in the mathematical formulations should refer to the cited references.

2. TWO-DIMENSIONAL MODELLING

In 1991, a new boundary element integral equation formulation for modelling cracks was reported by Aliabadi and portela[1]. The formulation was called the dual boundary element method due to its utilisation two integral equations; the displacement integral equation and the traction integral equation [2]. This development was a milestone in the developments of the boundary element method as for the first time allowed for automatic mixed mode crack growth simulation without a remeshing that is not posible with other numerical methods, most notable the finite element method. In figure 1, the application of the method to typical problem od multiple site damage is presented. As it can be seen from the figure, it is posible to model crack growth and coalesence without a need for remeshing. Furtermore, the crack paths are not inflenced with the distribution of internal meshes, which is inhenerent in domain type methods [3].

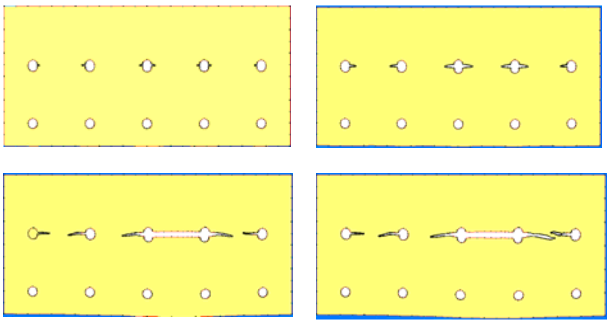


Figure 1: Multiple site damage.

3. THREE-DIMENSIONAL MODELLING

The BEM formulation for three-dimensional crack growth modelling was reported by Mi and Aliabadi and later Cisilino and Aliabadi. The strategy they developed for modelling crack growth consists of two parts. The first relates to the crack extension itself and is simply done by adding new elements along the crack front, whose dimensions and orientation are respectively given by the crack extension increment Δa and propagation vectors computed at geometrical points along the crack front. The second part is concerned with the modification of mesh around the crack front.

Consider a prismatic bar containing two identical offset semi-circular parallel edge cracks.
The dimensions of the bar, as well as the relative positions of the crack, scaled to the original crack radius are shown in figure 2. The bar is subjected to a remote tensile stress at its ends. Crack growth is estimated (see Cisilino and Aliabadi [6]) using Paris law.

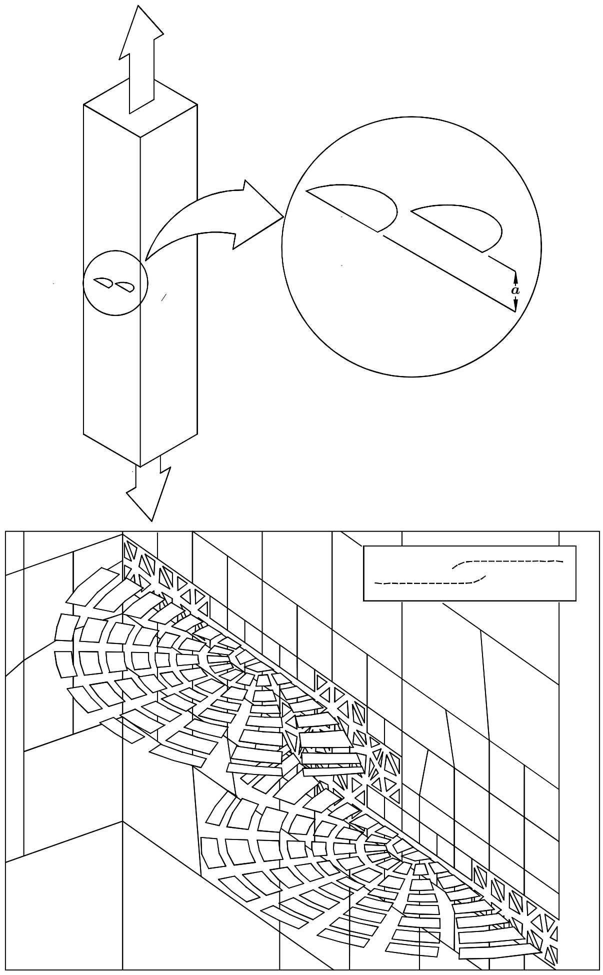


Figure 2: Growth of two offset semi-elliptical cracks.

2. REINFORCED PANEL UNDER TRANSVERSE SHEAR LOAD

A flat square panel reinforced with three Z-stringers (from the wing box of the B-52 Stratofortress) is subjected to the transverse load q=0,06MPa and it is considered to be simply supported on all sides. The material is aluminium 7075-T6 of Young Modulus E=71016MPa and Poisson's ratio v=0.33. The panel and the stringers are modelled with 13 thin plates in total. Each plate is divided into 32 quadratic elements. In Fig.3. deflection contours obtained by using a lrage deflection dual boundary element method is shown.

3. CURVED STIFFENED PANELS

Dirgantara and Aliabadi carried out a nonlinear fracture mechanics analysis of stiffened curved panel. The properties of the panel are as follows: thickness = 0.05 m; crack length 1 m, b=1m and 1/R = 0.1m-^{1}. Two stiffeners, with A =0.0175 m^{2} and I=3.5989*10^{-4} m^{4}, located at y = ± 0.5 m are attached to the shell. In the analysis, BEM shell mesh has 64 boundary elements and the stiffener is modeled with 5 nodal points each.

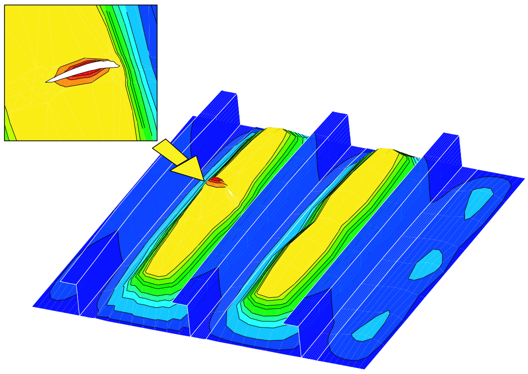


Figure 3: Modelling crack growth in a stiffened panel

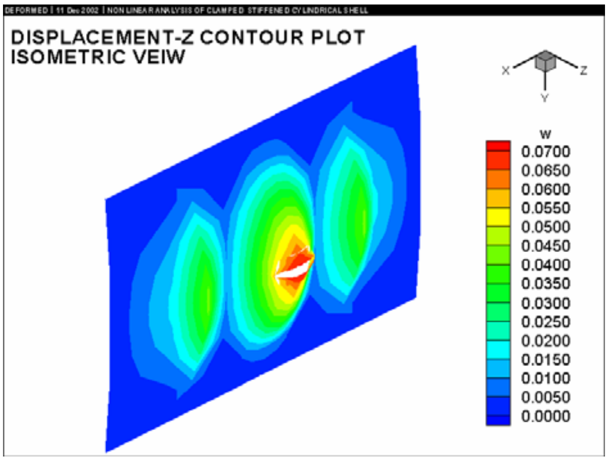


Figure 4: Skin bulging in a reinforced fuselaje panel.

4. BUCKLING OF THIN CRACKED PLATES

Recently Purbolaksono and Aliabadi[8] presented a dual boundary element formulation for buckling analysis of plates with cracks. They presented the problem of a rectangular plate with longitudinal central crack subjected to compression. Figure 5 presents the changes in the buckling mode of rectangular plate with aspect ratio 2. For the case of the short cracks (aspect ratio of crack length to width up to 0.25), the buckling modes are illustrated in figure 2c.

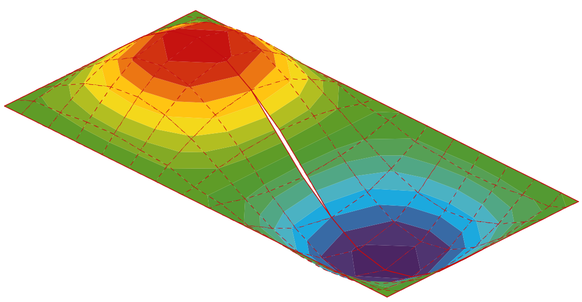
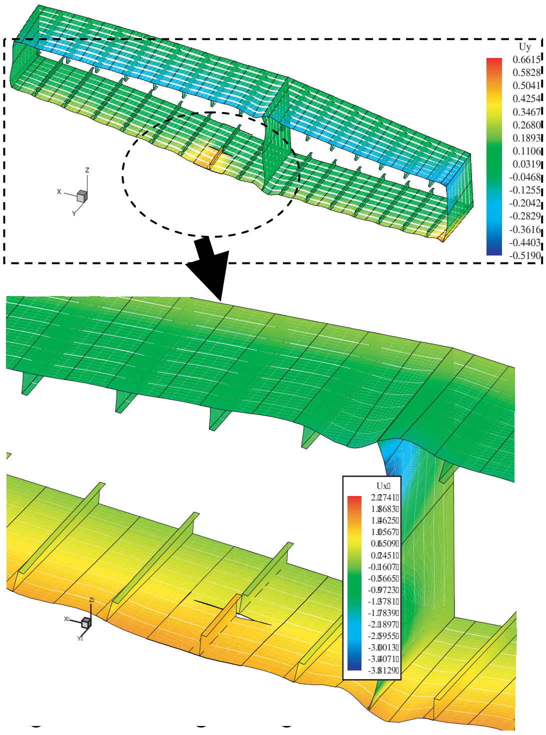


Figure 5. Buckling of a thin cracked plate.

5. MODELLING OF WING BOX SECTION

Recently Di Pisa and Aliabadi presented the application of the DBEM to modelling a wing section reinforced with stiffeners which are riveted to the skin.. The analysis which included nonlinear deflection were carried including a crack in a lower skin. The contour plot of the deflection is shown in figure 6.



In figure 7, result for the analysis of bonline flaw in a super plastic diffusion bonded section is shown.

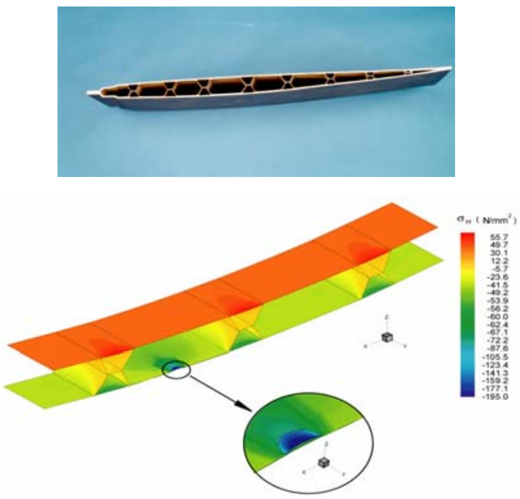


Figure 7. A bondline crack in a SPFDB.

6. SUMMARY

In this paper a brief review of the recent advances in the application of the boundary element method to Damage Tolerance Assessment of Aerostructures structures was presented. The method is shown to be capable of analyzing linear and nonlinear problems with boundary only discretization.

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