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Buckling and fracture behaviour of cracked thin plates under shear loading

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ABSTRACT

Thin-walled structural components are widely used in several engineering applications such as in aerospace, naval, nuclear power plant, pressure vessel, mechanical and civil fields. Since they are frequently characterised by a high slenderness, the safety assessment of such structural components requires to carefully consider the buckling collapse which can heavily limit their allowable bearing capacity. For very thin plates, buckling collapse can occur under compression, shear, or even under tension. In the present paper, the buckling and fracture collapse mechanisms in an elastic rectangular thin-plate with a central straight crack under shear loading are analysed. Different boundary conditions, crack length and orientation are considered. Through a parametric finite elements (FE) numerical analysis, the crack sensitivity of the collapse load of such a structural component is examined. The obtained results are discussed, and some interesting and useful conclusions are drawn. The collapse mechanism occurring earlier (buckling or fracture) is found by varying the fracture toughness of the material, and some failure-type maps depending on the geometrical parameters of the crack are determined.

1. Introduction

Slender metallic panels in structures such as pressure vessels, plates, box girders, naval and aerospace structural elements are usually subjected to in-plane loading.

Repeated loading in conjunction with manufacturing imperfections or mechanical discontinuities such as imperfect welding, corrosive environment, joints or transversal stiffening elements can easily produced, by nucleation and subsequent propagation, fatigue cracking and premature failure of such structural elements.

Usually cracks propagate mainly under predominantly tension conditions, towards regions of high tensile stresses when buckling failure does not appear first.

As is well-known, flaws can heavily affect the safety of structures, especially in thin-walled components, by facilitating the common modes of failure such as buckling, plastic flow or fracture. If the plate thickness is sufficiently small with respect to other plate sizes, buckling collapse under shear, compression or even tension can occur when fracture or plastic collapse does not precede the buckling one, and the presence of cracks can sensibly modify such an ultimate load.

Thin-walled panels are nowadays used in several engineering applications such as in aerospace, naval, mechanical, power industry and civil fields. An accurate evaluation of the safety levels in such structural components is crucial for their optimal design and economic reasons. Several studies have been carried out to determine the buckling load, responsible of the failure phenomenon in undamaged [1–5] or damaged plates [6–29] under various loading conditions such as compression [8,9,12,15,20–22], tension [8,10–14,16–22] and shear [23–27].

The influence of geometrical imperfections on the buckling phenomena in plates and shells has recently been examined: the influence of holes [14] and cracks on the buckling load of homogeneous [6–22] or composite [32–34] compressed, tensioned plates or shells under shear [23–27] and the effect of surface imperfections in cylindrical shells, pipes and rings [7,28–31,35] has quantitatively been evaluated.

Several approaches have been considered to tackle the problem under study: among them analytical approaches [6,16,17,31], numerical approaches [20,21,23–28,33], use of series expansion approaches in the context of analytical formulations [9,22], experimental studies [8,36] can be mentioned.

As is well-known, the buckling collapse in plates is heavily affected by the presence of a crack the detrimental effects of which are related to its length and orientation and to the boundary conditions of the structures being examined. Even if buckling under tension seems to be unrealistic, it easily occurs in common situations as a local phenomenon that develops in regions around defects such as geometric discontinuities, cracks or holes [28,29].

In the present paper, the sensitivity to crack length and orientation of the buckling load for elastic rectangular thin plates, characterised by different boundary conditions, under shear loading is examined.

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