Ultimate Strength Analysis of Grouted Tubular Joints Using Continuum Damage Mechanics Approach

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ABSTRACT

In the current paper, continuous damage mechanics is adopted to predict the fracture failure in the circular hollow section (CHS) joints, with the chord member reinforced using ultra-high strength grout. Isotropic damage is assumed and a single scalar damage variable has been adopted to describe the evolution of damage in the steel materials. The parameters for damage initiation and fracture are verified by a coupon test. FE models combining material damage effects are analyzed for grouted X joints under brace in-plane bending. The geometric parameters of these models are based on previous tests conducted in National University of Singapore (NUS). The numerical results show very close agreement with the experimental data. Further analyses regarding the effect of damage initiation strain, fracture strain, loading rate are also carried out.

KEY WORDS: Continuum Damage Mechanics; Grouted Joint; Ductile Fracture; Strength.

INTRODUCTION

As a result of Hurricanes Katrina and Rita in 2005, existing platforms will be required to resist significantly higher environmental actions than the originally design loads. This imposes a correspondingly higher demand on the strength of the critical tubular members and joints. For older platforms therefore, strengthening of the critical structural joints, through a viable engineering approach, becomes necessary to ensure the structural safety. Grouting technology proves to be an efficient method to strengthen or repair tubular joints. Experimental evidence (Tebbett, 1979; Choo and Chen, 2007) reveals that ductile fracture or punching shear failure are the most popular failure mechanisms for grouted joints under brace bending action or brace axial tension. However, conventional numerical approaches based on continuum mechanics do not represent the ductile fracture failure which involves material separation and thus invalidates the primary assumption in continuum mechanics.

At the micro-scale level, material fracture is characterized by the nucleation, growth and coalescence of voids. At macro-scale level, this process is characterized by the continuous deterioration of the material stiffness, often called “softening”, as shown in Fig. 1. The material response is initially linear elastic, a - b, followed by plastic yielding with strain hardening, b - c. Point c identifies the material state at the onset of softening. Beyond this point, the stress-strain response c - d is governed by the evolution of the degradation of the stiffness in the region of strain localization. c – d’ can be viewed as response that the material would have followed in the absence of softening. When the softening is large enough to offset the effect of material strain hardening, instability occurs in the shear bands, causing unstable propagation of the material defect or damage.

Fig. 1 Softening behavior of materials

Various constitutive models (Borst, 1987; Ngo and Scordelis, 1967; Ewalds and Wanhill, 1984) have been developed to simulate the formation of void and cracks, such as the smeared crack model, the discrete crack model and fracture mechanics models. However, these models become inefficient when applied to a real structure or a large-scale laboratory structural specimen with complicated geometry and loading conditions. The smeared crack model introduces an instant decrease in the structural stiffness, which may not describe the material damage evolution and often cause numerical instabilities. As for discrete crack models, continuous modification of topology would be necessary to simulate the formation and propagation of the crack. In addition, cracks are only allowed to form at the element boundary and hence the direction of crack is mesh-dependent. The main problem associated with fracture mechanics is the need to assume the location and size of crack before the analysis can be performed. These assumptions can be quite subjective and experience based. Moreover, the general application of fracture mechanics requires the interaction