Appraisal Of Simulation Tools For Fracture In Steel Components Under Seismic Load

A. Tola¹, I. Koutromanos², M.R. Eatherton²

¹Graduate Student Researcher, Dept. of Civil and Environmental Engineering, Virginia Tech
²Associate Professor, Dept. of Civil and Environmental Engineering, Virginia Tech

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Introduction

- Fracture initiation and propagation in steel components (i.e. beams, columns, braces) due to cyclic load can be studied through full-scale tests or using finite element simulations and damage accumulation laws for Ultra-Low-Cycle-Fatigue (ULCF).
- Damage accumulation laws should be applicable to a wide range of stress states that are associated with fracture in steel components.
- Factors affecting ductile fracture:
  - **Triaxiality** ($\eta$)
    - Normalized indicator of the pressure.
    - Larger $\eta \rightarrow$ Faster damage accumulation.
  - **Lode angle** ($\theta$)
    - Indicator of the deviatoric part of the stress tensor.
    - $\theta = f(J_2, J_3)$, $\xi = \text{“Lode angle parameter”} = \cos(3\theta)$
  - **Effective Plastic Strain** ($\bar{\varepsilon}_p$)
- Some of the existing damage accumulation laws are mainly dependent on the triaxiality, while existing efforts focus on adding the Lode angle dependence to account for stress states associated with shear and low triaxiality. The outcomes of a law proposed by Huang & Mahin (2010) are explored in this study.

- This study is part of a larger research project under current development at Virginia Tech:
  "Computational Simulation Framework to Capture Ductile Fracture in Steel Structural Systems"
Components considered

Steel Plate Shear Wall (Phillips, 2016)  
Beam-to-Column Moment Connection (Eatherton et al, 2013)  
Brace (Fell et al, 2009)

FE models & damage accumulation law used satisfactorily reproduced the global force-deformation response prior to fracture,
Fracture initiation from experiments: Delayed → for stress states governed by high Lode angle parameter (i.e. the beam-column connection).

Too early → for stress states with widely varying Lode angle parameter (i.e. the brace).
Fracture propagation

Steel Plate
Shear Wall

Satisfactorily prediction of the location where fracture initiates

Moment Connection

Brace

Direction / Speed of crack propagation were partially satisfactory only.
Conclusions

<table>
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<tr>
<th>Satisfactory</th>
<th>Partially Satisfactory</th>
<th>Potential causes for disagreement</th>
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<tbody>
<tr>
<td>- Global force-deformation response.</td>
<td>- Instant of fracture initiation</td>
<td>- Element removal technique.</td>
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<td>- Location of rupture occurrence.</td>
<td>- Characteristics of crack propagation.</td>
<td>- Not accounting for Lode angle dependence in the ULCF law used.</td>
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- Damage accumulation laws for ULCF that include the effects of Triaxiality and Lode angle could potentially yield better predictions. Some of those laws include the work of Cao et al. (2014), Smith et al. (2014), Wen & Mahmoud (2016), among others.

Current work at VT is exploring fracture initiation in thin steel members extracted from the flats and corners of two A1085 HSS tubes with different thicknesses (0.25 in. and 0.5 in.), under ULCF loading.

A reasonable range of triaxiality and Lode angle is projected to be obtained through the testing of cylindrically notched specimens under a) cyclic-axial and b) combined cyclic-axial-torsional loading.

Finite element models together with a selected damage accumulation law will be used to simulate the results from the testing program.

Full-scale testing of a brace will be also performed.

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