Department for Transport

ACCEPTABILITY OF DYNAMIC FINITE ELEMENT ANALYSES – MATERIAL FAILURE APPROACH

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Department for Transport (Central)

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Acceptable Failure Criteria

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- Preamble
  - Analysis / assessment is robust and self-standing
  - Sufficient margin against failure available
  - Persons involved are well experienced in the area
  - Good trail of QA documentation available

Acceptable Failure Criteria

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- Introduction
  - To elicit a “strain” based assessment criterion
  - Simple representative UN Type B package
  - “Accident” condition of transport – Para’ 727 (a) of TS-R-1 2009
    - 9 m “drop” on an unyielding “target” “so as to suffer maximum damage”
    - No follow-on fire test envisaged

Acceptable Failure Criteria

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- System Description
  - Thin walled hollow end-capped cylinder of typical Carbon Steel
    - 300 mm OD / 1200 mm Length / 10 mm wall thickness
    - Mass and Content (unspecified)
      - Calculated mass of ~95 kg
      - Simulated content of 13,754 N (in force, see later slide)
    - Drop orientation
      - Package longitudinal axis at 45^o to horizontal for ease of modelling

Acceptable Failure Criteria

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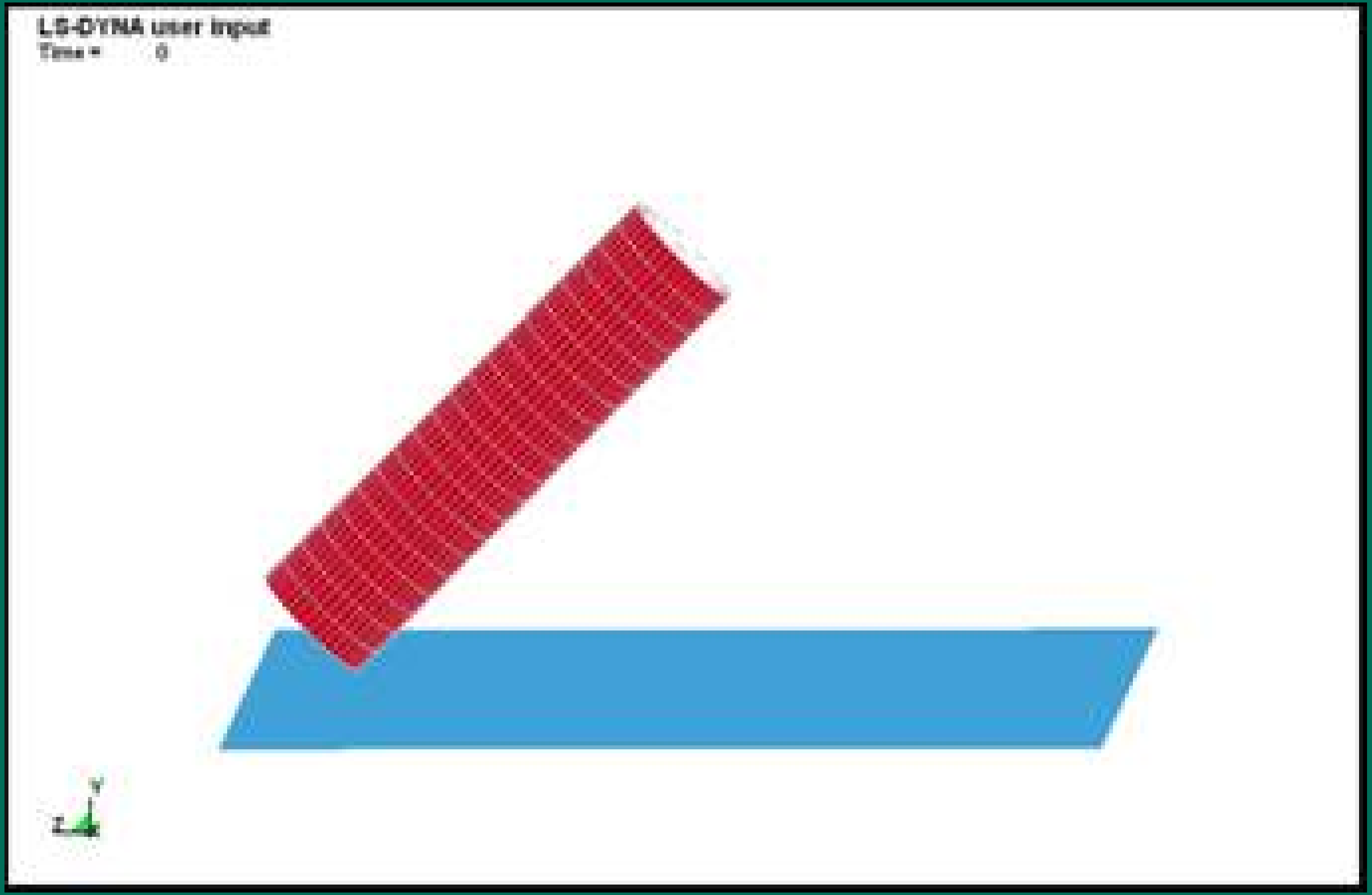
- Finite Element Model
  - Linear “Shell 163” element has been used for the “cylinder” as well as the “rigid” target (1400 elements and 1402 nodes)
    - 3 integration points through thickness (default)
    - General contact definition (“node to surface”)
    - Static and Dynamic Friction
    - ~13 ms^{-1} terminal velocity before impact
    - 0.175 second overall duration of simulation
    - No welds have been modelled
    - Default tolerance values
    - Package content simulated as 1kgf (9.81 N) vertical force at each node

Acceptable Failure Criteria



Acceptable Failure Criteria

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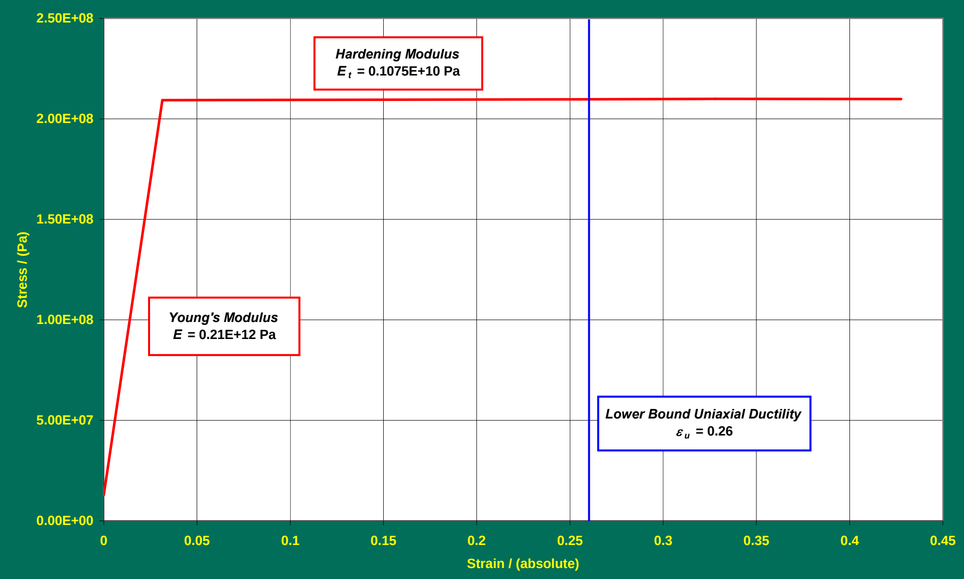
- Material Data (Physical & Tensile Properties)
  - Typical Carbon Steel from BS1501:Part 1 1980
  - Elastic – Plastic with Bilinear Hardening (*Mat_Plastic_Kinematic*)



Acceptable Failure Criteria

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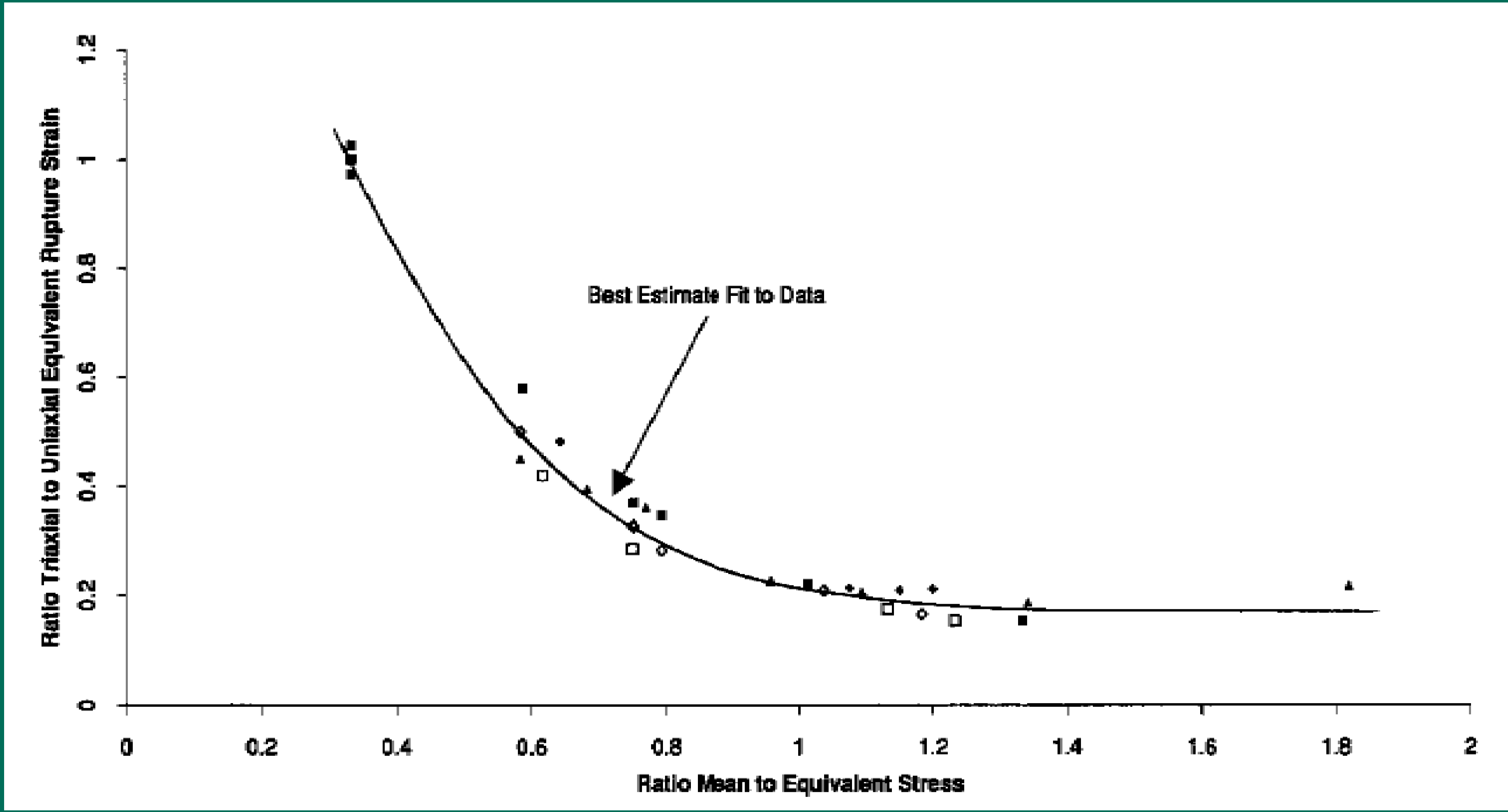
- Multi-axial stress state "Strain – based" criterion – an example
  - R3 Impact Assessment Procedure – "strain (and energy) acceptibility"
    - Predominant "plastic" response – "strain-based"
    - Multiaxial Stress State: rupture strain $\varepsilon_r \neq \varepsilon_u$ (uniaxial ductlity or "elongation")
      - $\varepsilon_r = f(m)$
      - Multiaxiality factor $m = \sigma_h / \sigma_{VM}$
      - $\sigma_h = -\,trace(\sigma_{kk}) / 3$, *where* σ_{kk} *is the principal stress tensor*
      - $\sigma_{VM} = \sqrt{(^3/_2 \sigma'_{ij}\,\sigma'_{ij})}$, *where* σ'_{ij} *is the deviatoric stress tensor*

Acceptable Failure Criteria



Acceptable Failure Criteria

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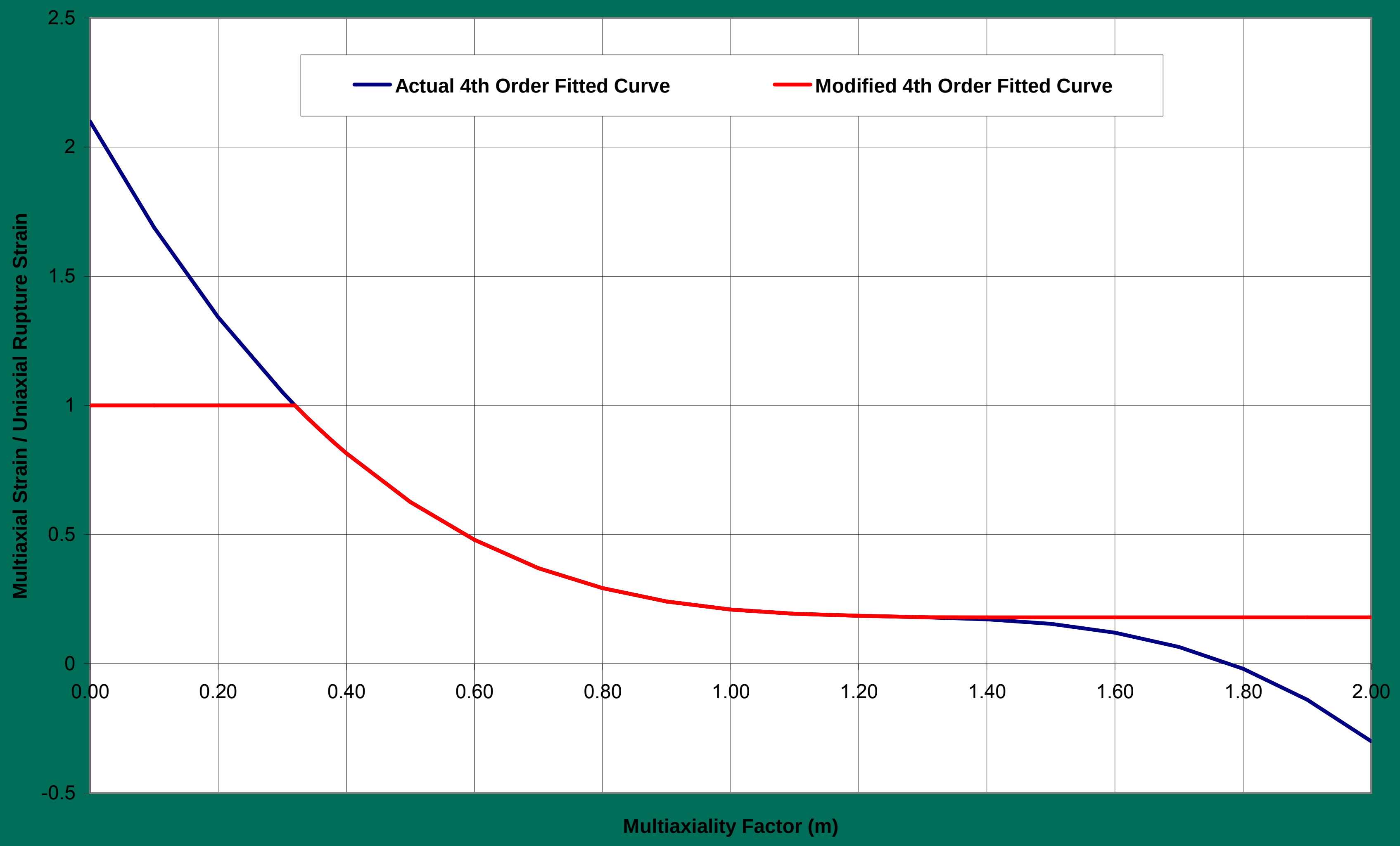

Acceptable Failure Criteria

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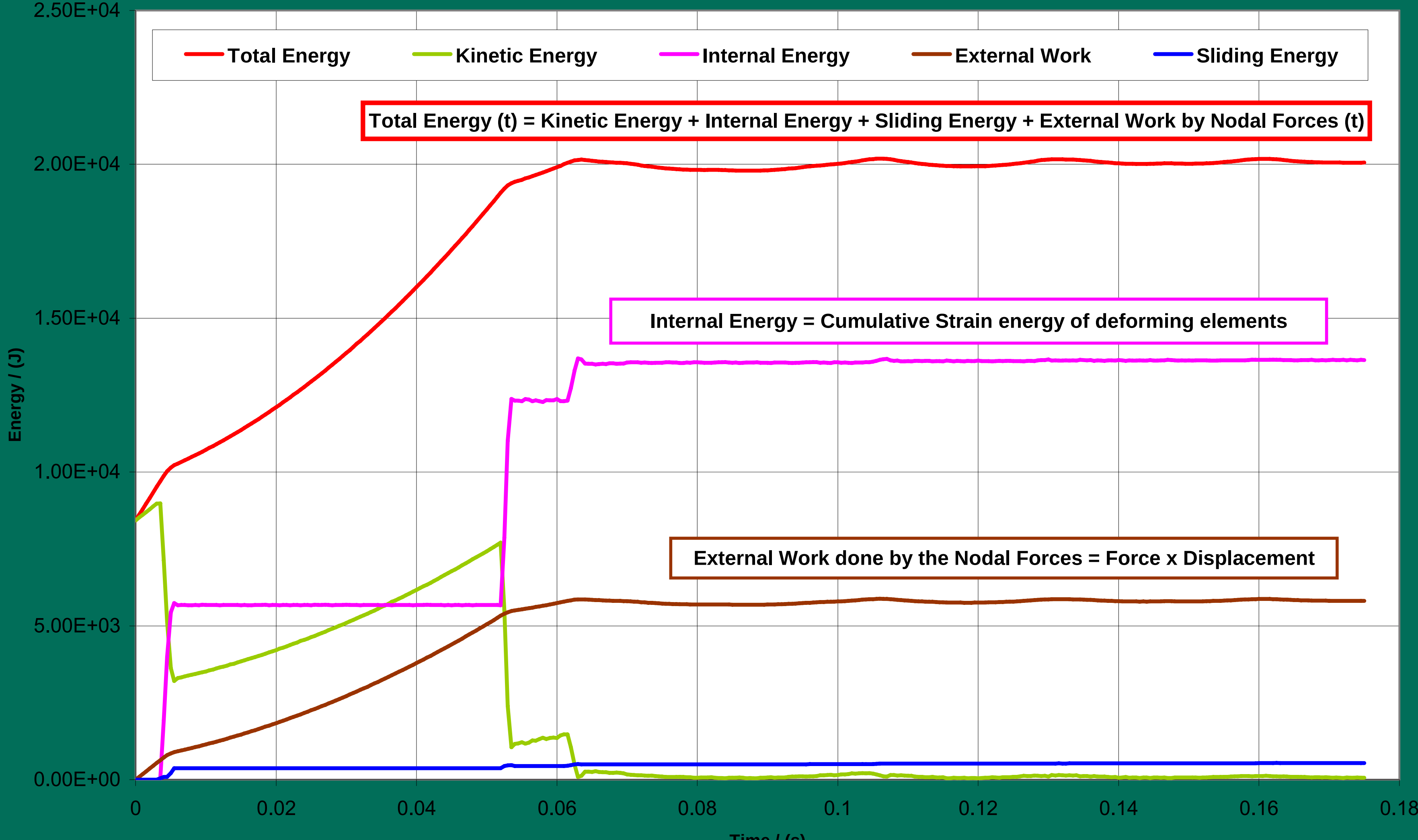
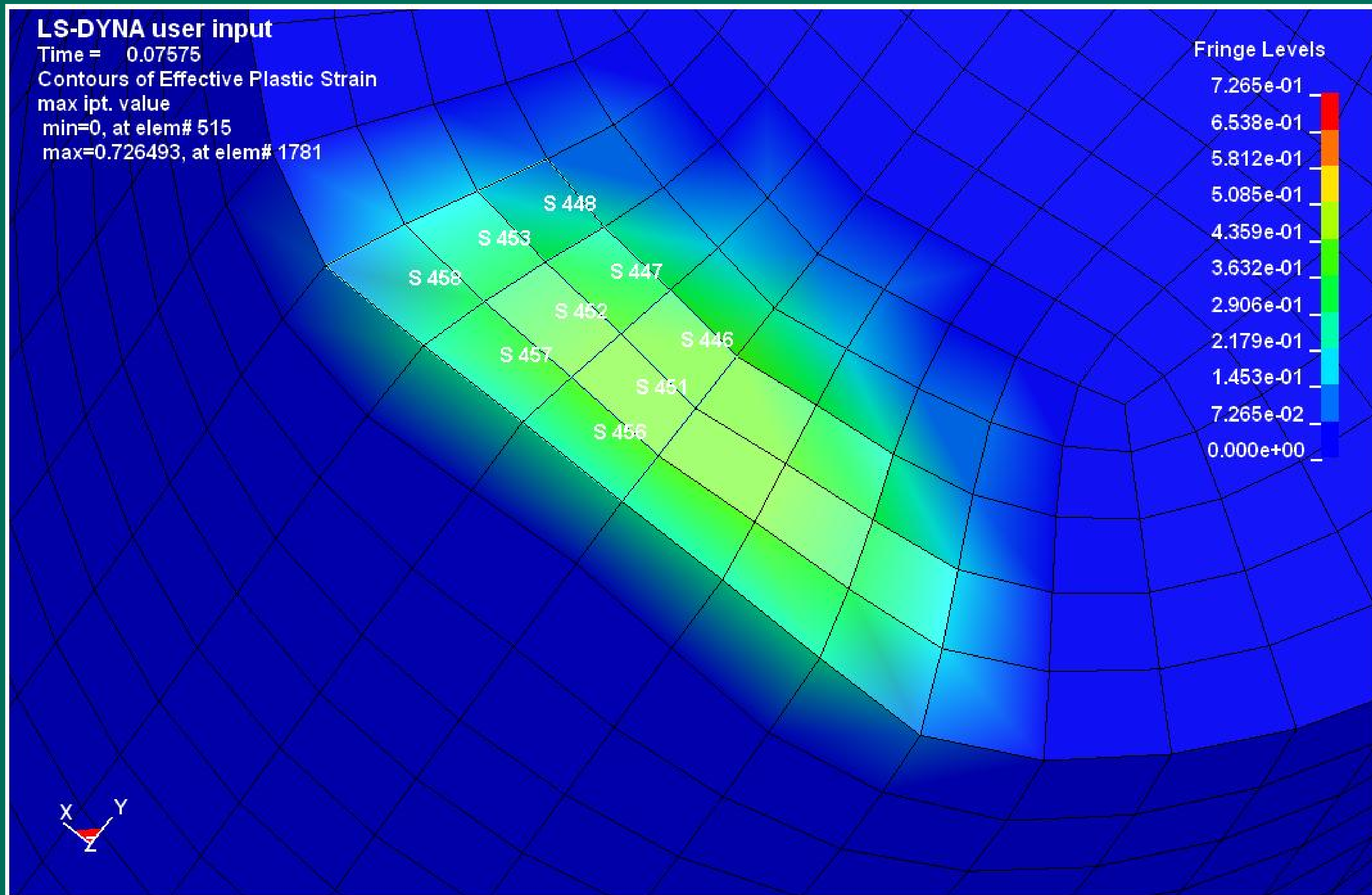
- Energy Histories



Acceptable Failure Criteria

- EPS



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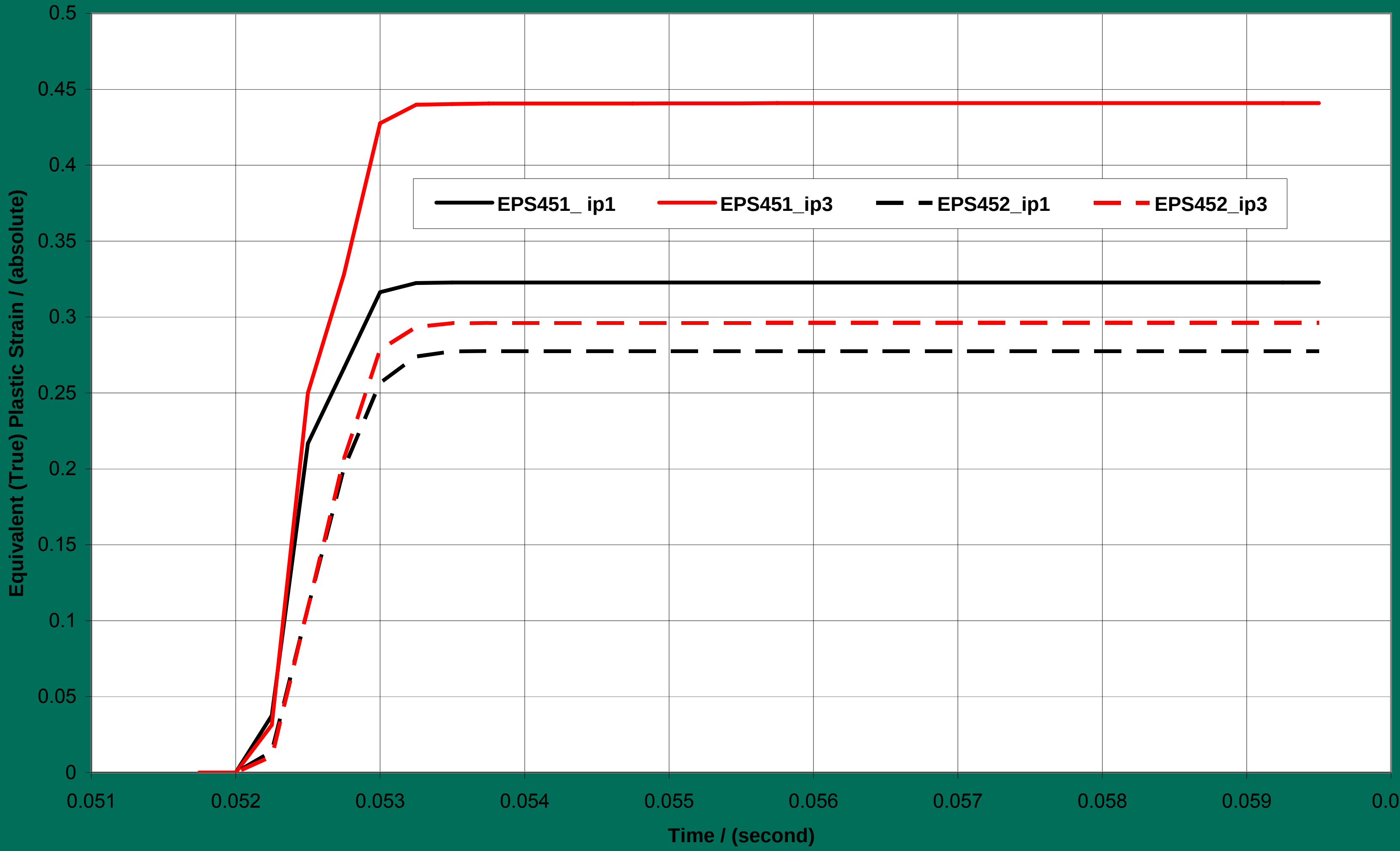
- EPS history for E451 & E452



Acceptable Failure Criteria

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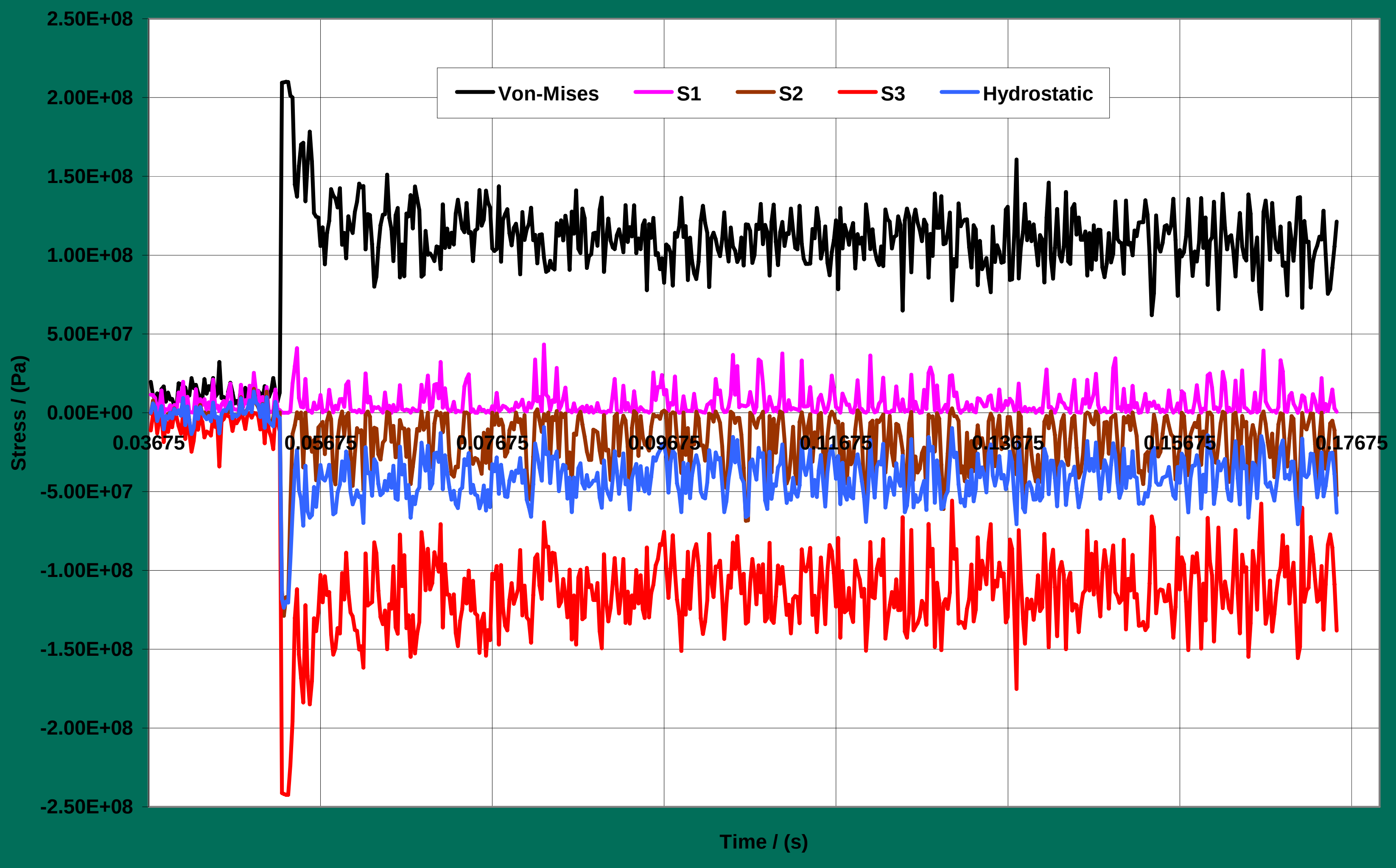
- Stress histories for E451 (ip#3)



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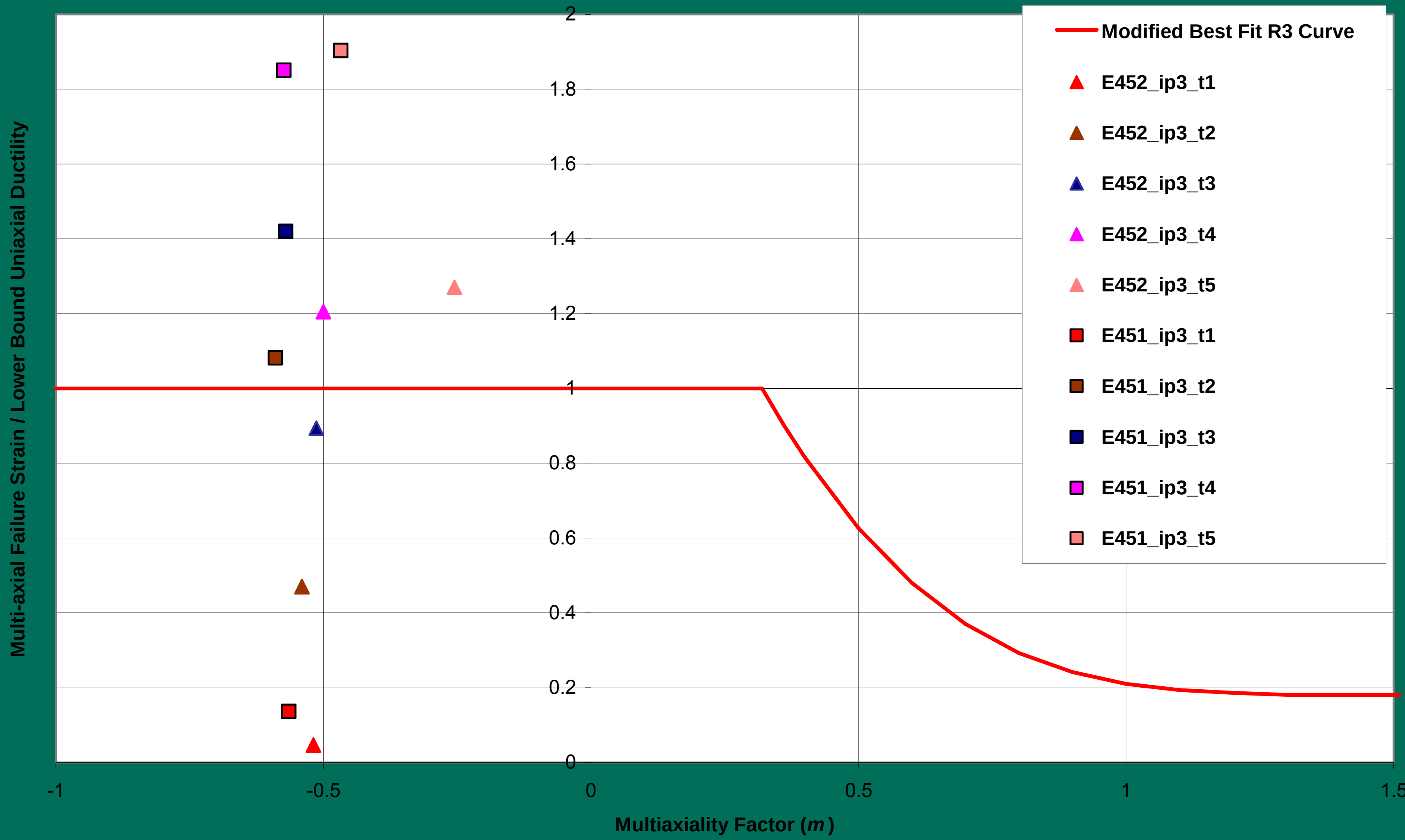
- R3 Assessment for E451 (ip#3)



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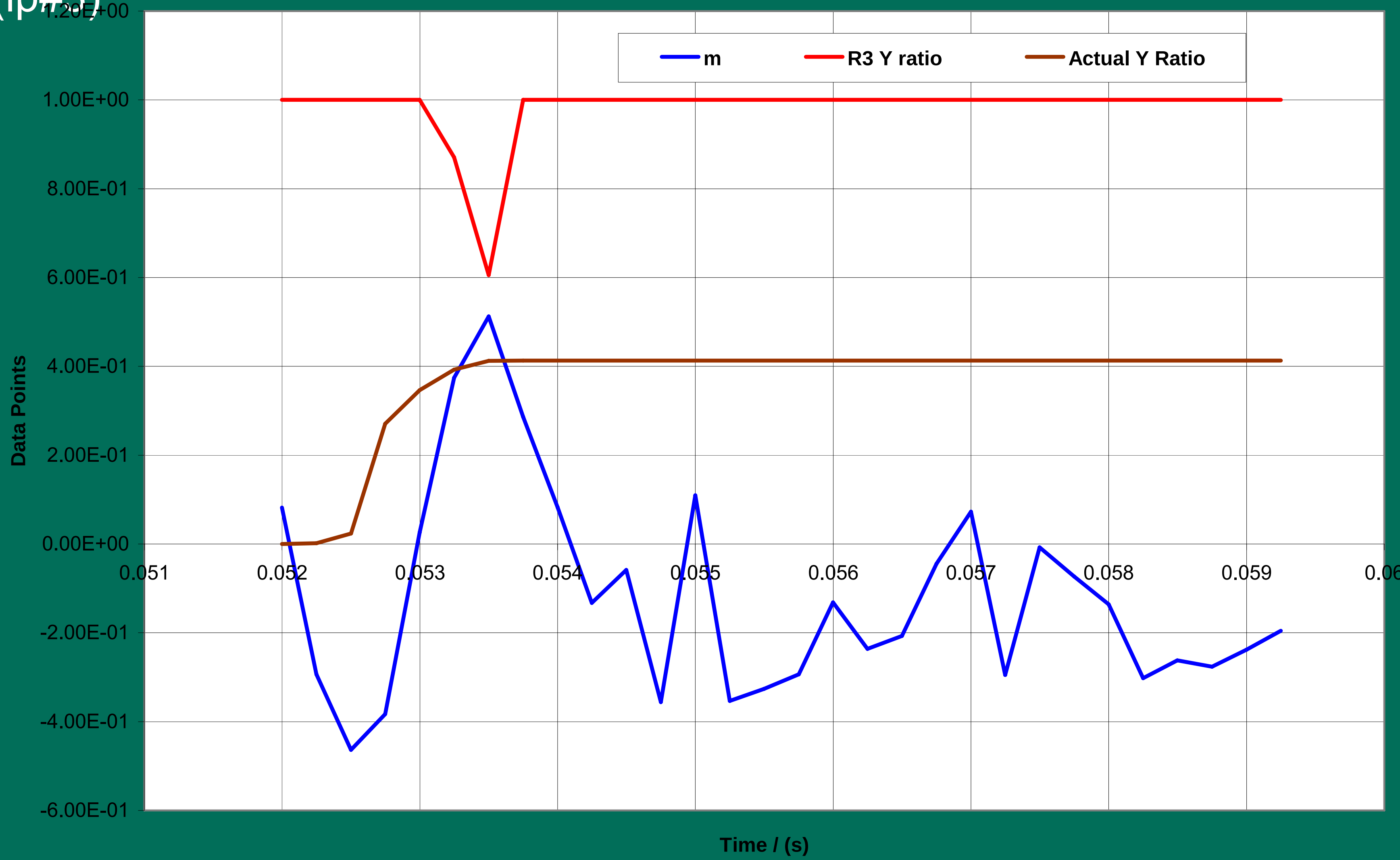
- E441 (ip#3)



Acceptable Failure Criteria

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- Conclusions
  - E451 failed due to very high accumulated plastic strain >> lower bound ε_u
  - This procedure needs to be followed for each element with plastic strain (ε^{pl}_{eqv})
  - Pessimism
    - Lower bound material properties
    - Bilinear hardening curve (e.g. strain rate ~400 s^{-1} "high" – significant work hardening ignored)
    - No shock absorbing material used
  - Future work planned
    - Appropriate factor of safety (FOS) against allowable multiaxial failure strain
    - Compare with ASME VIII Division 2 Section 5.3 ("Protection Against Local Failure")

Acceptable Failure Criteria

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- Questions if any please