Blast Testing of PFP Systems – Small Scale Understanding of a Large Scale Problem

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PFPNet Conference 2024

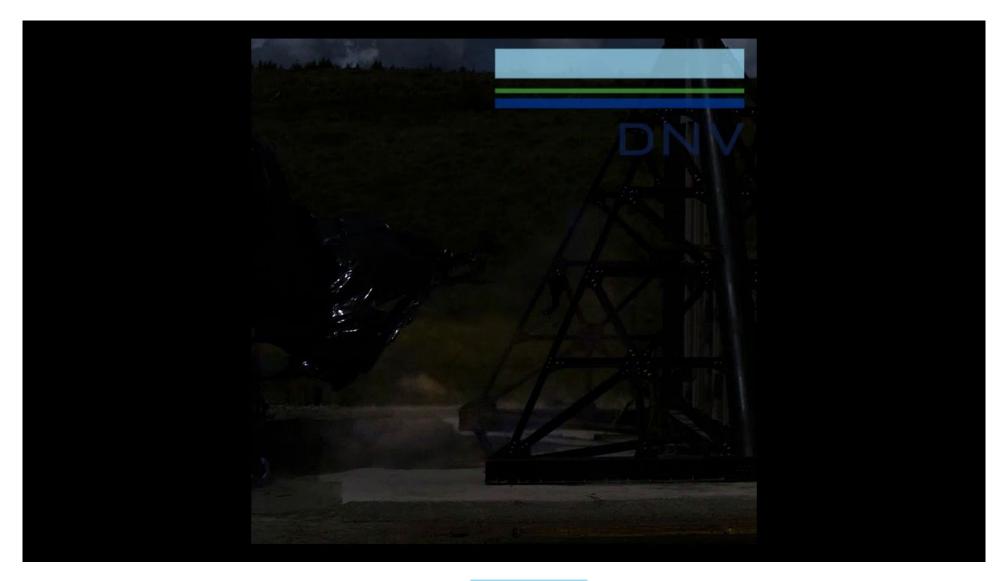
"Explosions" - deflagrations in congested geometries



Cam: Phantom v.8031 AcqRes: 1728 x 600 Rate: 3000 Exp: 10 μs



Cyclic response of structural elements (overpressure)





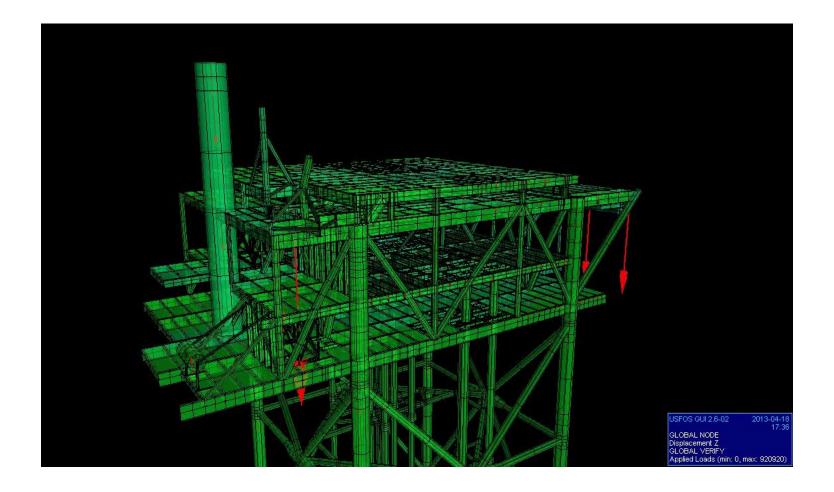
Cyclic response of structural elements (drag loading)





"Explosions don't load PFP coatings – structures do."

"The PFP coating system is mostly a passenger aboard the moving structure."



Themes & concepts raised during group meeting on 04 Sept 2024

Actions &

boundary

conditions

Temperature

Substrate strain

(uniaxial, biaxial,

strain rate, plasticity)

Cyclic nature of

substrate response

(compressive & tensile

alternating)

Substrate twisting

(e.g. members

undergoing lateral-

torsional buckling)

Inertial effects as

substrate accelerates

or decelerates

(if relevant?)

Substrate geometry

(corners, re-entrant

features. etc.)



PFPNet Conference 2024 **Definition of Definition of Fundamental Development of** System level material damage performance material system limit response properties limit states states envelopes Extrapolation of small "Localised damage" Analogous to Stress-strain Ductile-brittle relationships in tensile scale test results to transition temperature limit state isodamage or higher level structural (if relevant to product) (overall performance & compressive pressure-impulse conditions of barrier is not curves widely used in systems compromised) blast engineering (matrix & reinforced) Onset of "yield", or Extent of failure on onset of tensile Failure strains as a e.g. complete rupture, as "Widespread damage" Multi-variable "lookfunction of segment of deckhead, appropriate limit state up" charts/tables reinforcement content truss element or wall (overall performance (temperature, es of barrier is substrate strain, of temperatur Onset of "yield", or coating thickness) compromised, with onset of compressive Cohesive properties to Potential for some residual represent de-bonding propagation of crushing, as capacity) (continuum methods, localised damage to appropriate Applicable to range of or traction-separation become more loading regimes methods?) extensive range "Catastrophic (monotonic, cyclic, Onset of cohesive damage" limit state elastic, plastic) failure Cohesive damage (overall performance (normal stress) ¥ model, damage of barrier is essentially Perhaps the definition initiation & evolution. negligible in Onset of cohesive of "performance mixed mode (shears & subsequent fire) failure classes"? normal) (shear stress) Suite of above properties at suitable

Definition of small scale test coupons, apparatus & methodology Properties for use in general purpose FEA studies & to inform testing requirements

temperatures

(establish DBTT)

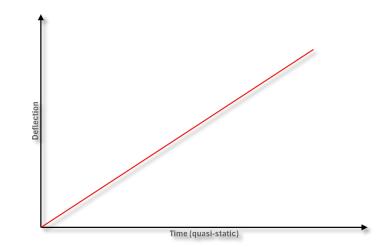
Guidance on how to apply results from small scale testing at macro scale

Define larger scale tests?

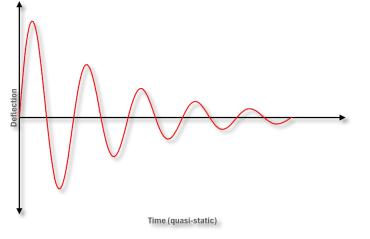
Definition of material damage limit states allows high level comparison of materials Develop limit states applicable to structural systems or large assemblies

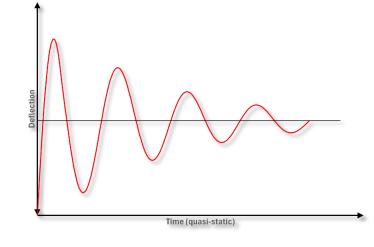
Convenient, easily accessible information for designers & specifiers

Conceptual outline of testing



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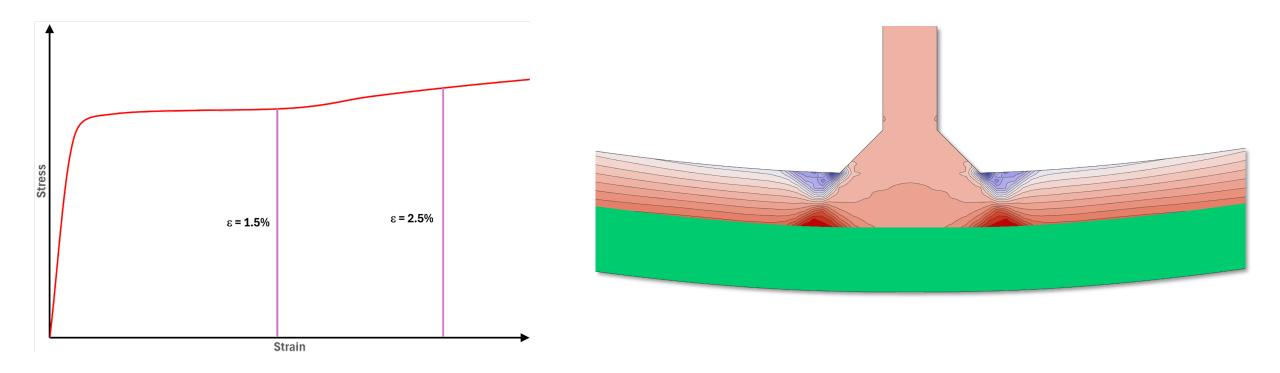


Forcing function

- Displacement controlled
- Coupon suitable for loading in both directions
- Separate tests at each specified temperature

Steel test coupon

Stress (σ), strain (ϵ) & coupon configuration



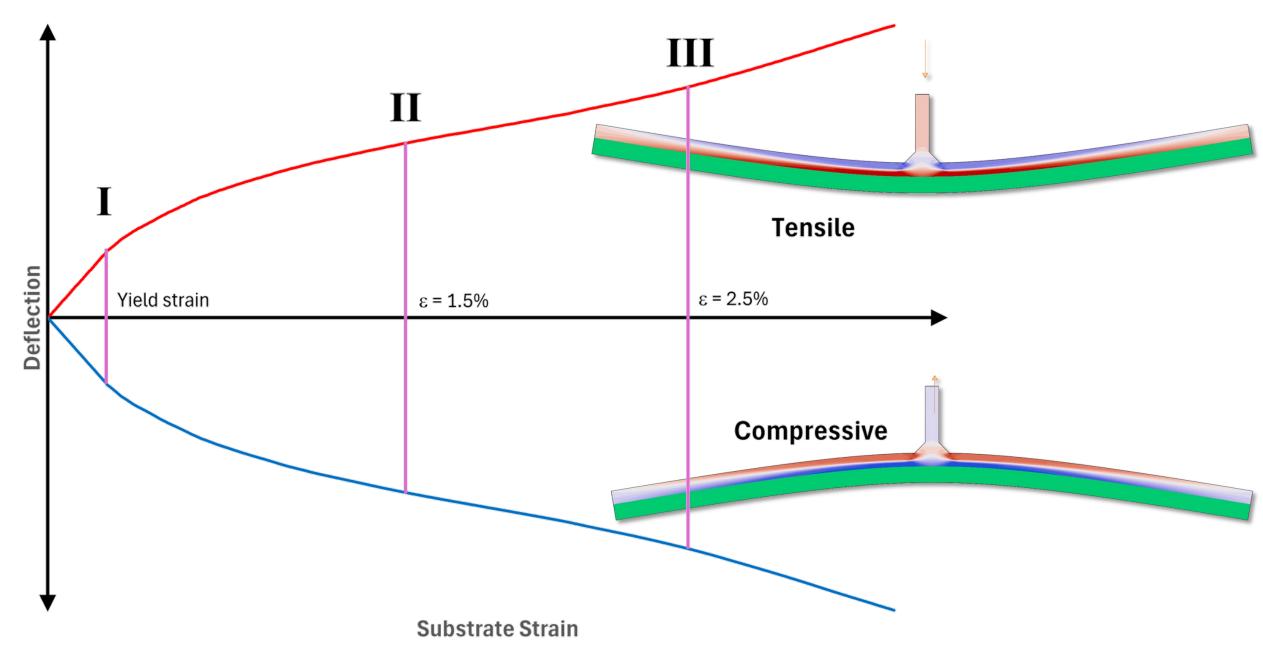
Appropriate strain limits?

- Design codes (Euro, AISC, NORSOK)
- Strains often limited to 5% (i.e. significant plasticity)
- However, it seems improbable that test strains need exceed 1.5% to 2.5% especially at lower temperatures

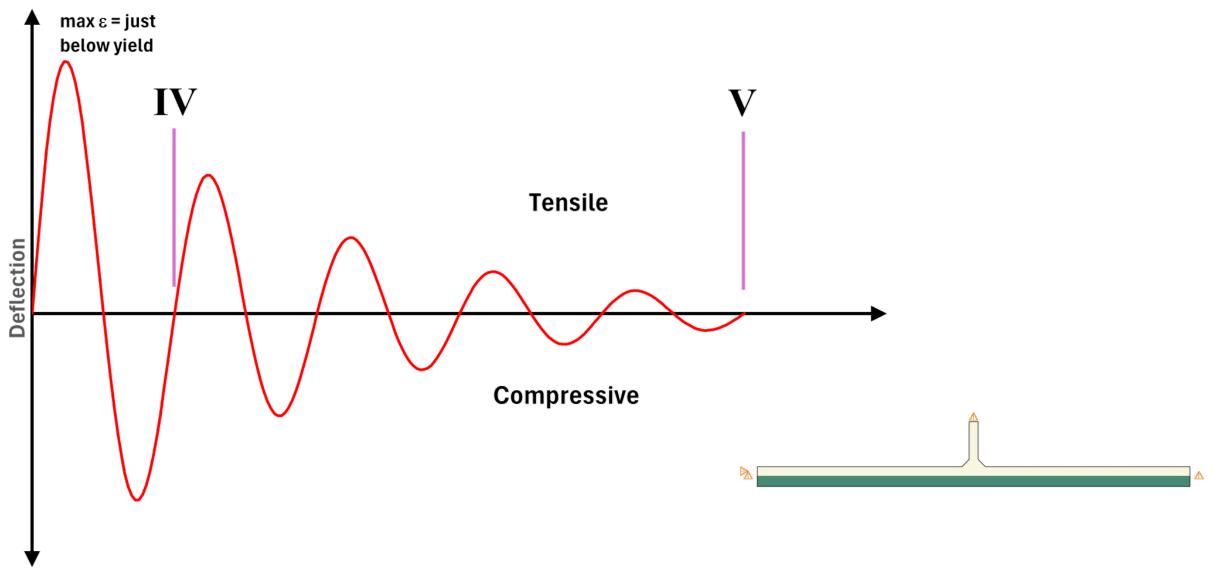
Coupon configuration

- Full penetration butt welded "driving plate"
- Mimic beam web/flange junction
- Produces some variation in substrate stains
- Many options can be envisaged to provide such variation

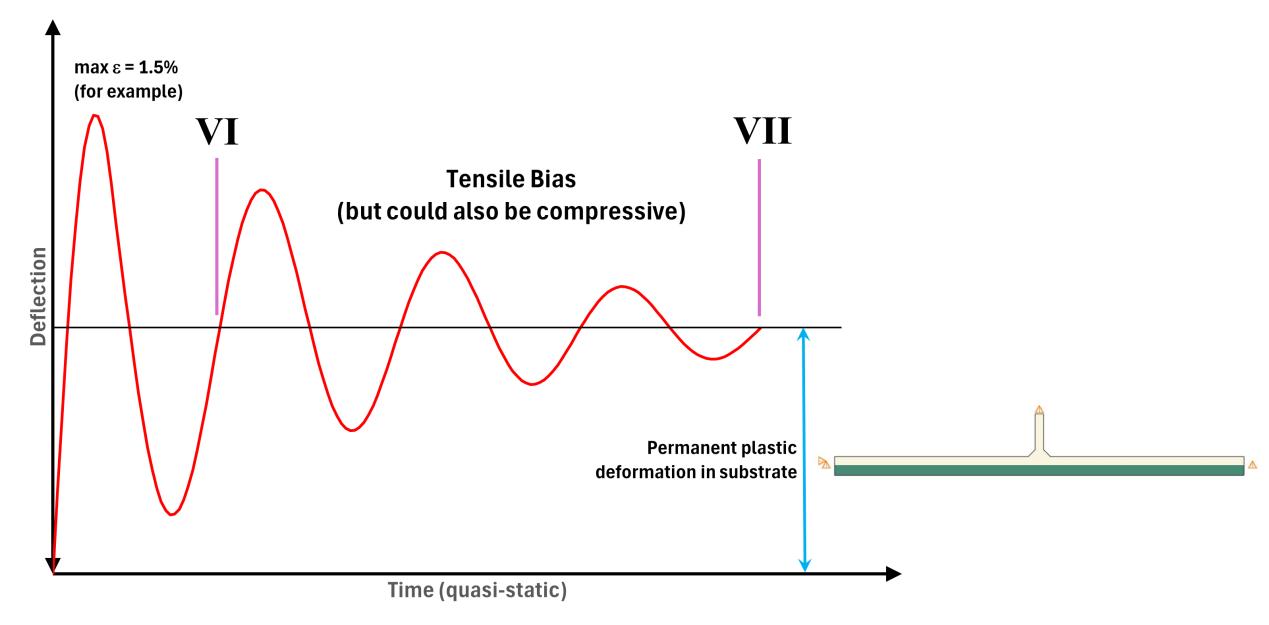
Monotonic testing



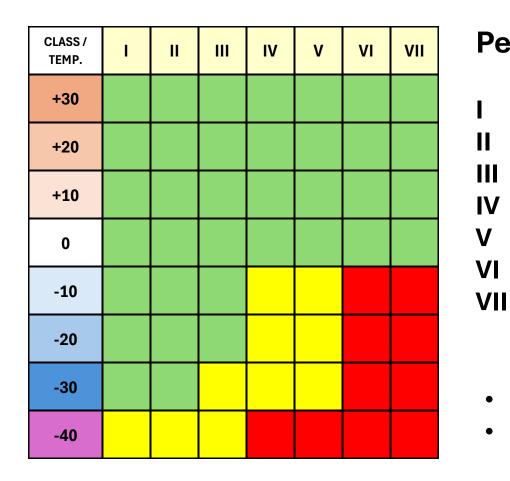
Cyclic elastic testing



Cyclic plastic testing



Coating performance "map" concept



Performance Classes

- Intact at onset of yield in substrate
- Intact at 1.5% strain in substrate
- Intact at 2.5% strain in substrate
 - Intact after one cycle up to yield
 - Intact after multiple cycles in elastic range
- Intact after one cycle up 1.5% strain
- Intact after multiple cycles with residual plasticity

(monotonic)

(monotonic)

(monotonic)

- Convenient format for specifiers & purchasers
- Provides for comparison between products and/or manufacturers
- Other variables can be brought to bear (e.g. coating thickness, degree of reinforcement, substrate enhancements, etc)

Concluding remarks

- Reliable retention of PFP coatings as structures respond to explosion loading is essential for subsequent fire performance
- Explosions expose coated structures to cyclic displacements, up to and beyond yield in the substrate
- Substantial insight into the tenacity of the coating can be gained by relatively simple testing:
 - Adherence & robustness under steadily increasing strain & curvature
 - Adherence & robustness under damped, cyclic loading (inc. in plastic range)
 - Sensitivity to temperature
 - Validation of analytical and FEA material models
- NOTE: If quasi-static performance is inadequate, the prospects under dynamic loading are not good
- Simple testing should be amenable to definition in Codes & Standards
- Limitations of simple testing may help define scope of larger scale/complex testing