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Code Case Validation of Impulsively Loaded EDS Subscale Vessel

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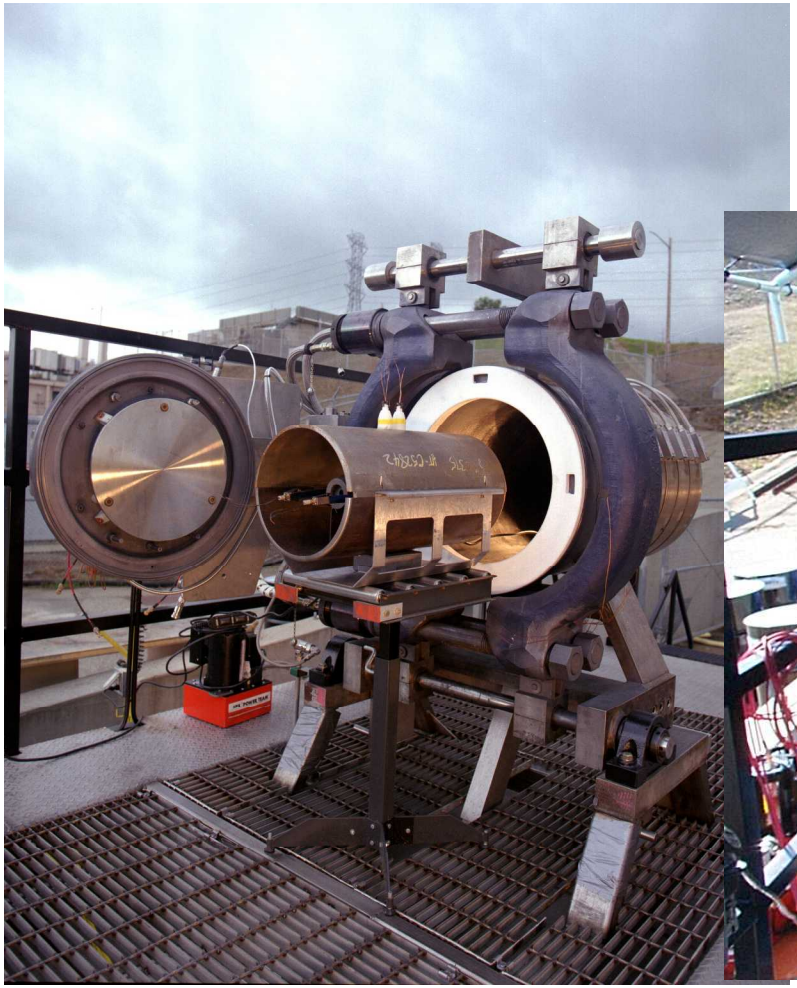
Explosive Destruction System (EDS)

Full Scale



Introduction

- EDS is used to contain and destroy recovered chemical munitions for PMNSCM
- Subscale vessels used to study vessel response over a wide range of load levels
- Subscale vessel is checked against ASME Code Case for Impulsively Loaded Vessels.

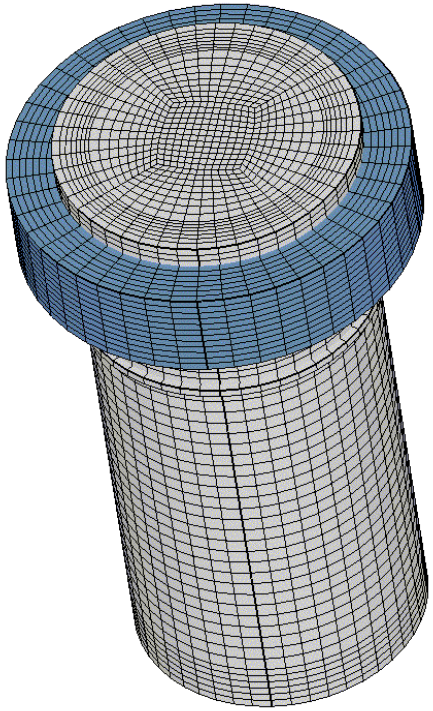
Explosive Destruction System (EDS)

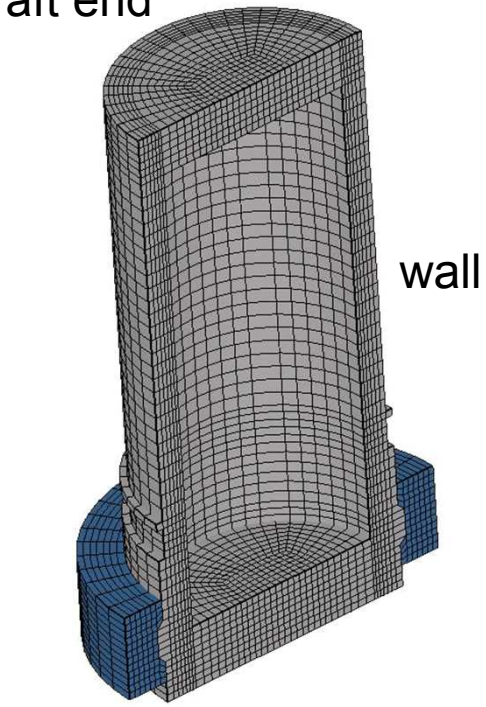
Subscale

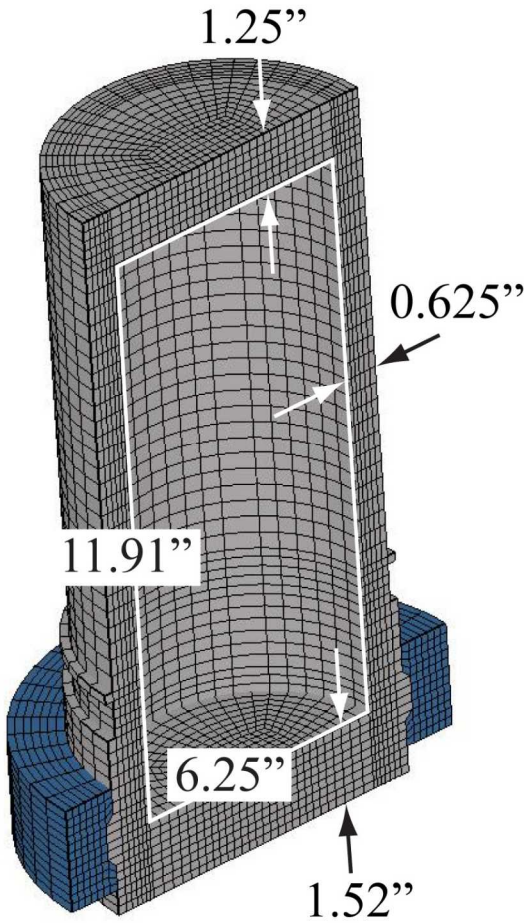
Overview

- Determine subscale vessel rating based on the Code Case
- Check fatigue and fracture limits
- Comments on overtest situations

Mesh of EDS subscale vessel





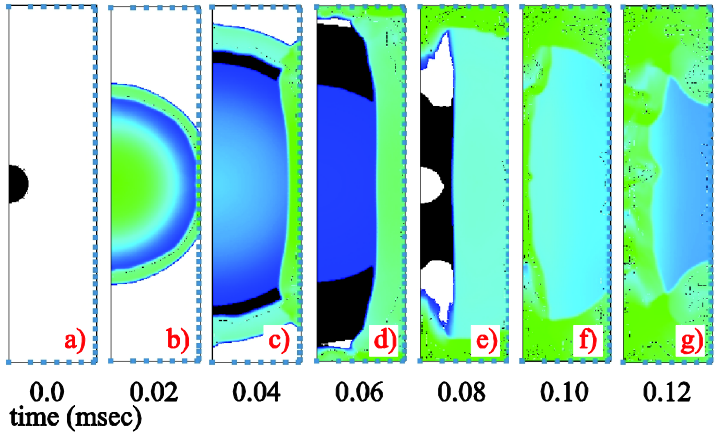


Density	0.278	lb/in^3
Elastic modulus	30,000	ksi
Poisson’s ratio	0.3	
yield strength	40.4	ksi
tangent modulus	145.0	ksi

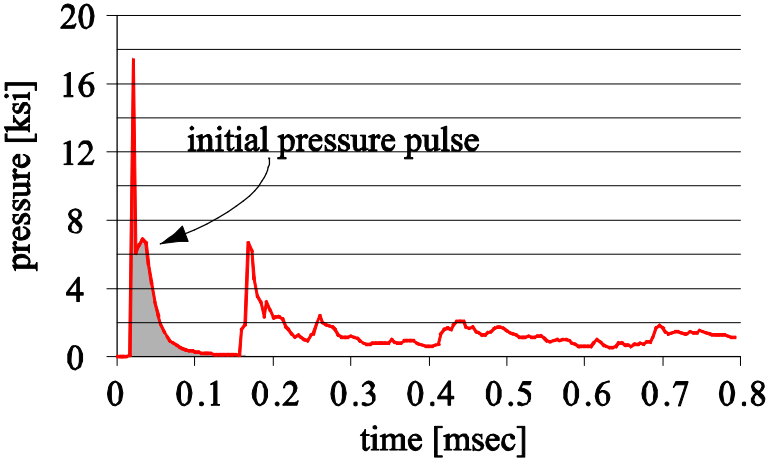
316 SS material properties used for plastic-kinematic material model in LS-DYNA

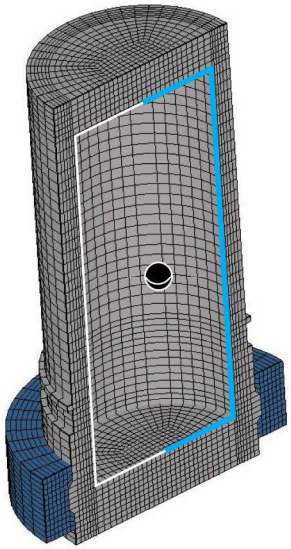
Impulsive ?

CTH pressure profiles



typical pressure-time history





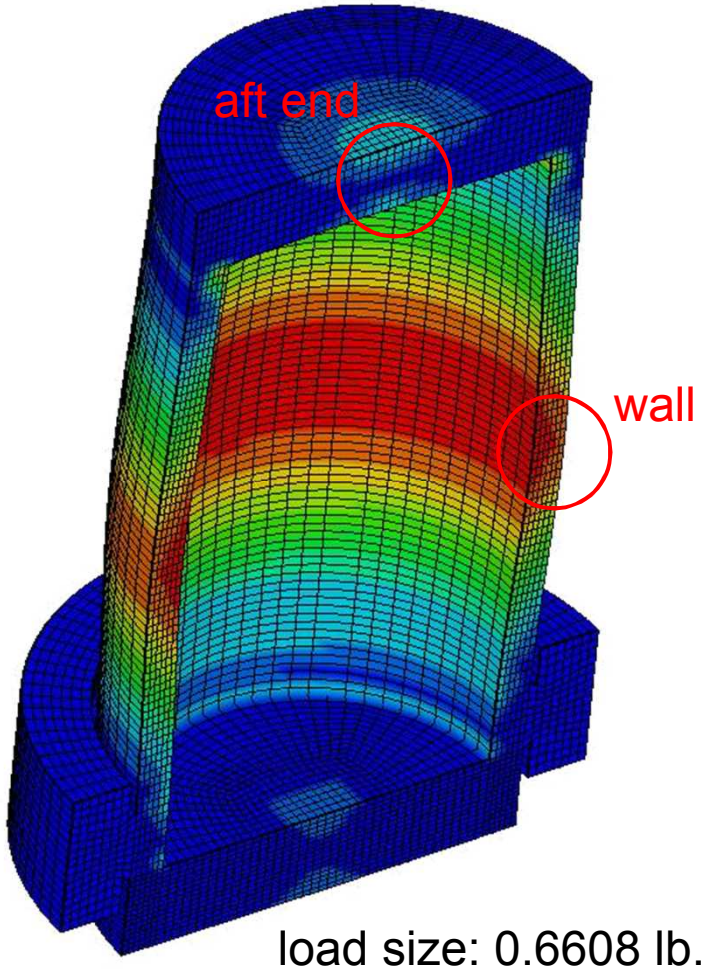
- ΔT = ~0.09 msec
- f_0 = ~690 hz (τ = 1.45 msec)
- $\Delta T/\tau$ = 0.062 < 0.35 (Code Case)
- loading is impulsive

Single-shot vessel response

Plastic strain at wall and aft end
for single-shot event

explosive size (pounds)	equivalent plastic strain (%)					
	exterior aft	center aft	interior aft	exterior wall	center wall	interior wall
0.0305	—	—	—	—	—	—
0.0458	—	—	—	—	—	—
0.061	—	—	—	—	—	—
0.0916	—	—	—	—	—	—
0.1068	—	—	—	—	—	—
0.1526	—	—	0.025	—	—	0.0215
0.1831	0.051	—	0.114	0.0377	0.0286	0.0746
0.2441	0.165	—	0.496	0.0849	0.0611	0.174
0.3052	0.353	—	0.732	0.250	0.156	0.248
0.5286	1.156	0.298	1.032	1.789	1.650	1.722
0.6608	2.100	0.396	1.806	6.804	7.105	7.542

All loads level at pounds of TNT



load size: 0.6608 lb.

Strain Limits

Membrane strain limit: $\varepsilon_m = 0.5 (\varepsilon_i + \varepsilon_o) \leq 0.2\%$

explosive size (pounds)	equivalent plastic strain (%)					
	exterior aft	center aft	interior aft	exterior wall	center wall	interior wall
0.0305	—	—	—	—	—	—
0.0458	—	—	—	—	—	—
0.061	—	—	—	—	—	—
0.0916	—	—	—	—	—	—
0.1068	—	—	—	—	—	—
0.1526	—	—	0.025	—	—	0.0215
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0.6608	2.100	0.396	1.806	6.804	7.105	7.542

All loads level at pounds of TNT

choose: 0.2441 lb.
elastic core at aft end

Rating for membrane strain limit: 0.2441 lb.

Strain Limits

Bending strain limit: $\varepsilon_b = 0.5 (\varepsilon_i - \varepsilon_o) \leq 2.0\%$

explosive size (pounds)	equivalent plastic strain (%)					
	exterior aft	center aft	interior aft	exterior wall	center wall	interior wall
0.0305	—	—	—	—	—	—
0.0458	—	—	—	—	—	—
0.061	—	—	—	—	—	—
0.0916	—	—	—	—	—	—
0.1068	—	—	—	—	—	—
0.1526	—	—	0.025	—	—	0.0215
0.1831	0.051	—	0.114	0.0377	0.0286	0.0746
0.2441	0.165	—	0.496	0.0849	0.0611	0.174
0.3052	0.353	—	0.732	0.250	0.156	0.248
0.5286	1.156	0.298	1.032	1.789	1.650	1.722
0.6608	2.100	0.396	1.806	6.804	7.105	7.542

All loads level at pounds of TNT

bending not significant at wall due to pure tension

aft is close to bending limit for load level of 0.6608 lb.

Rating for bending strain limit: 0.6608 lb.

Strain Limits

Peak strain limit: $\varepsilon_{max} \leq 5.0\%$

explosive size (pounds)	equivalent plastic strain (%)					
	exterior aft	center aft	interior aft	exterior wall	center wall	interior wall
0.0305	—	—	—	—	—	—
0.0458	—	—	—	—	—	—
0.061	—	—	—	—	—	—
0.0916	—	—	—	—	—	—
0.1068	—	—	—	—	—	—
0.1526	—	—	0.025	—	—	0.0215
0.1831	0.051	—	0.114	0.0377	0.0286	0.0746
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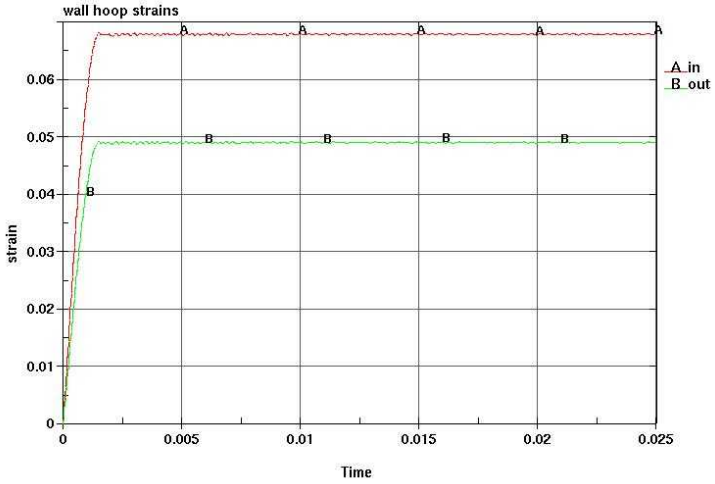
All loads level at pounds of TNT



wall exceeds peak strain at load level of 0.6608 lb.

Rating for peak strain limit: 0.6608 lb.

Strain-based plastic collapse

explosive size (pounds)	equivalent plastic strain (%)					
	exterior aft	center aft	interior aft	exterior wall	center wall	interior wall
0.0305	—	—	—	—	—	—
0.0458	—	—	—	—	—	—
0.061	—	—	—	—	—	—
0.0916	—	—	—	—	—	—
0.1068	—	—	—	—	—	—
0.1526	—	—	0.025	—	—	0.0215
0.1831	0.051	—	0.114	0.0377	0.0286	0.0746
0.2441	0.165	—	0.496	0.0849	0.0611	0.174
0.3052	0.353	—	0.732	0.250	0.156	0.248
0.5286	1.156	0.298	1.032	1.789	1.650	1.722
0.6608	2.100	0.396	1.806	6.804	7.105	7.542

All loads level at pounds of TNT

- Based on Code Case, we want to design vessel with an impulse that is 175% of the design-base impulse, that will not cause a plastic instability state.
- Assume plastic instability state to occur with formation of at least two plastic hinges.

Conservative to choose 0.3052 lb load level

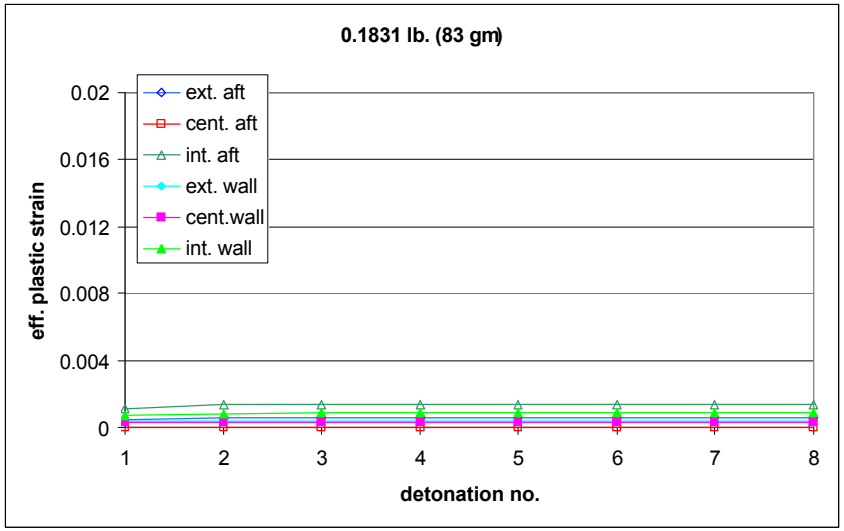
Rating for plastic collapse: Load = (1 / 1.75) * 0.3052 lb = 0.1744 lb.

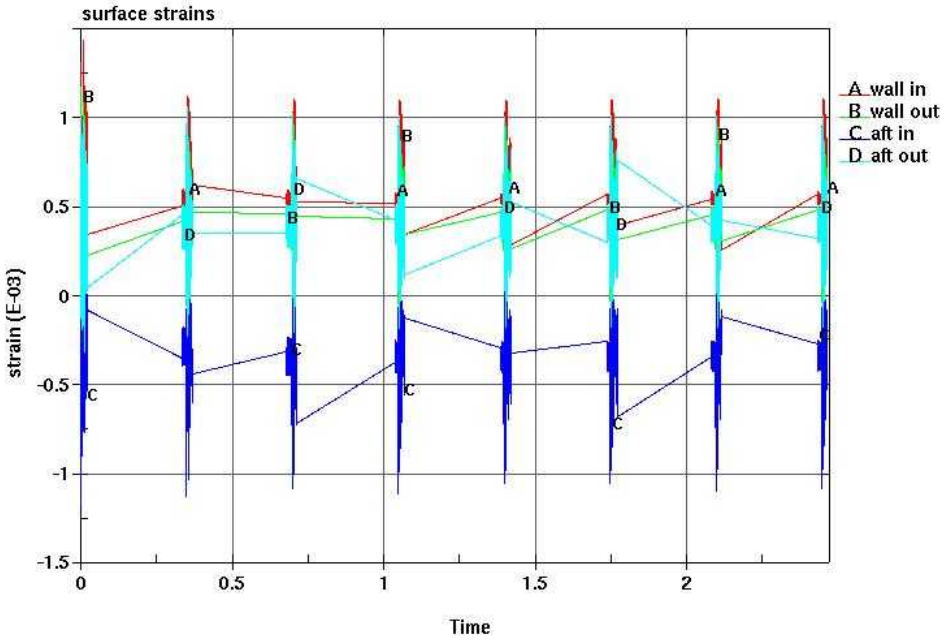
Vessel rating summary:

Membrane strain limit: 0.2441 lb.
Bending strain limit: 0.6608 lb.
Peak strain limit: 0.6608 lb.
Plastic collapse: 0.1744 lb. ← governs

Look at vessel response for successive detonations at 0.1831 lb., 0.2441 lb., and 0.6608 lb. TNT

Multiple-shot vessel response

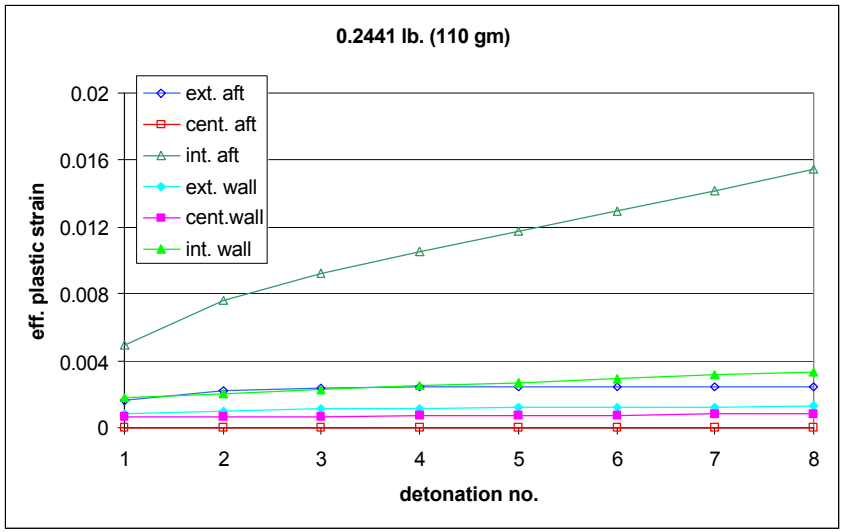


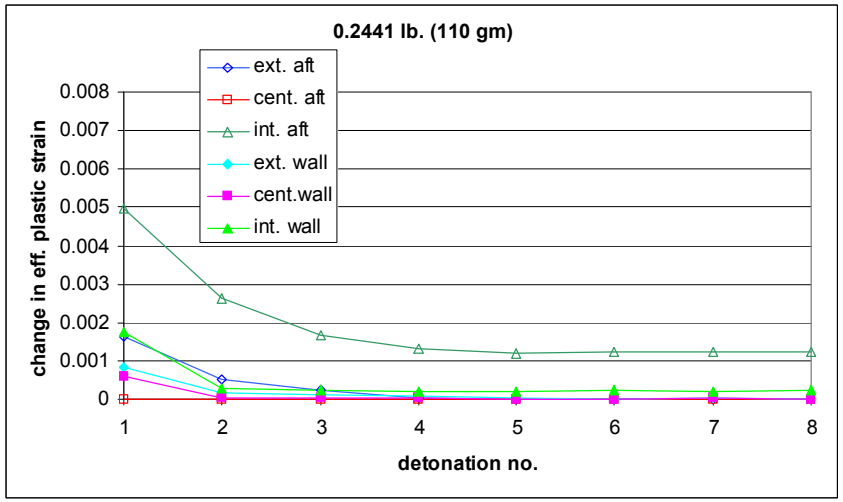


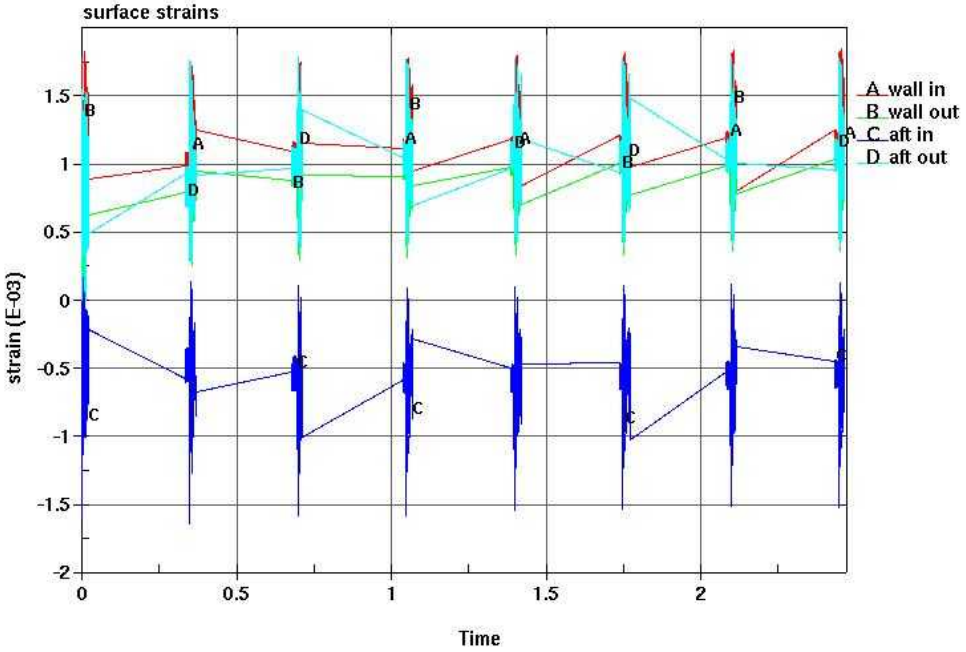
8 successive detonations at 0.1831 lb. load level

very little increase in plastic straining with successive detonations.

Multiple-shot vessel response







8 successive detonations at 0.2441 lb. load level

plastic strain increases at interior aft end faster than at wall

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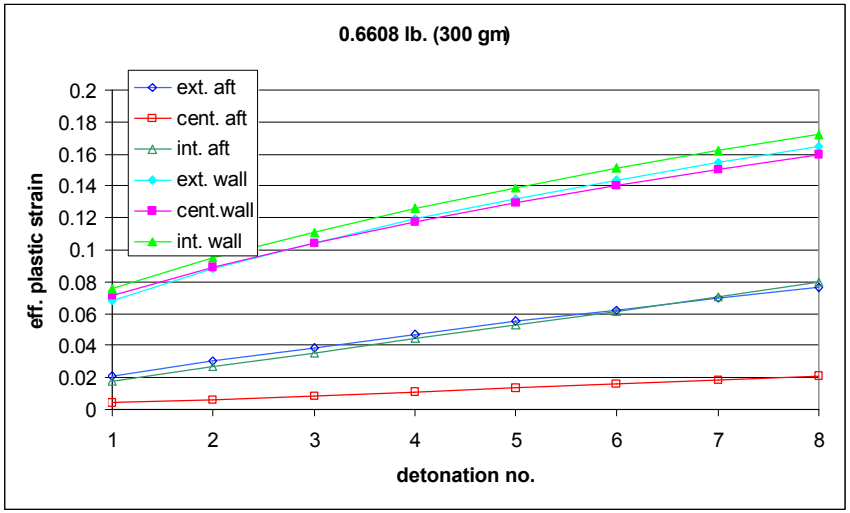
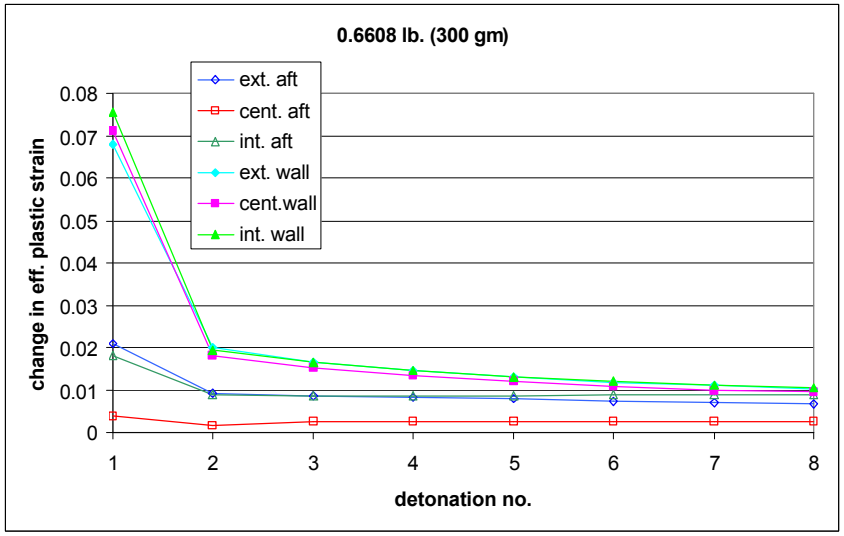
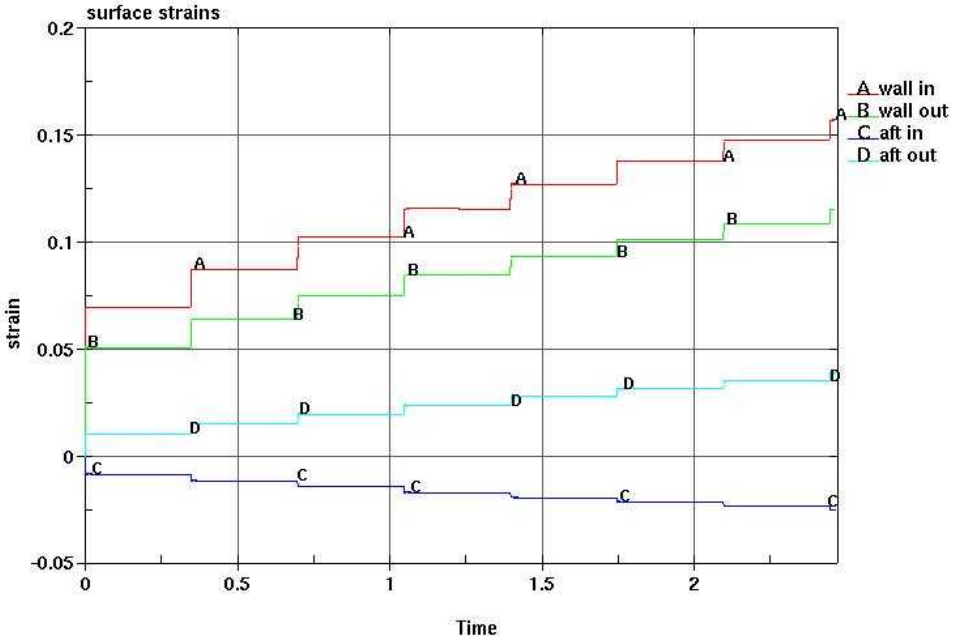
Multiple-shot vessel response







8 successive detonations at 0.6608 lb. load level

- plastic strains increase at vessel wall faster than at aft end.
- decrease in incremental plastic strain due to strain hardening
- no failure in material model

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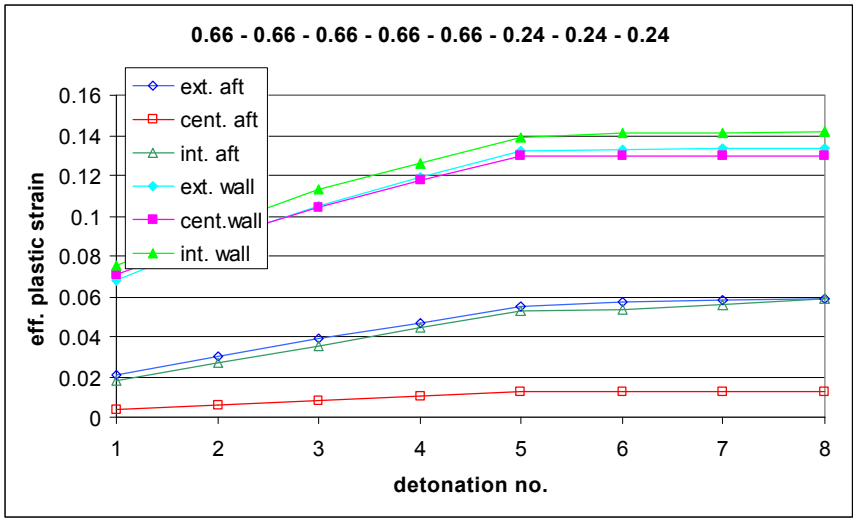
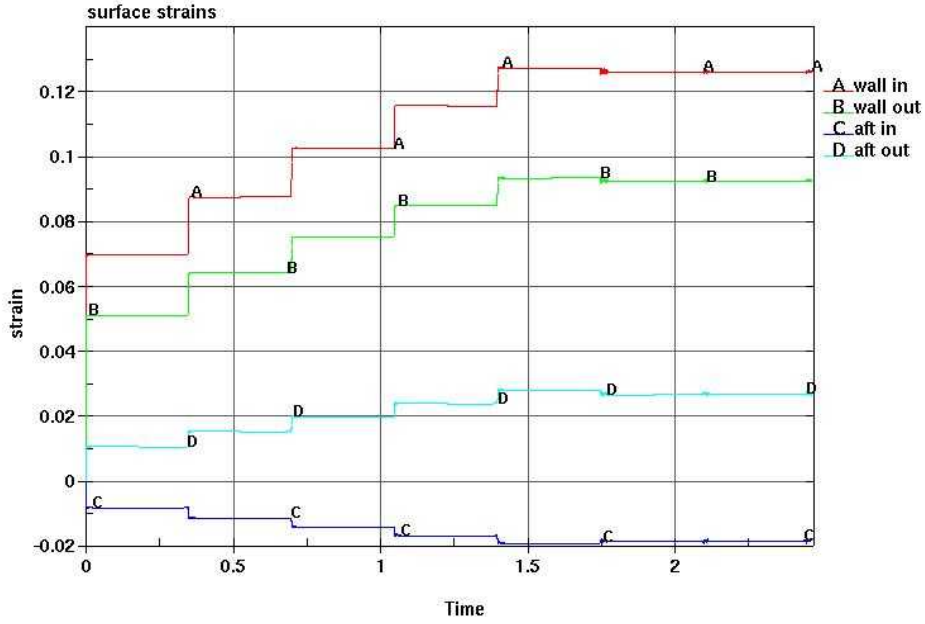
Variable-shot vessel response

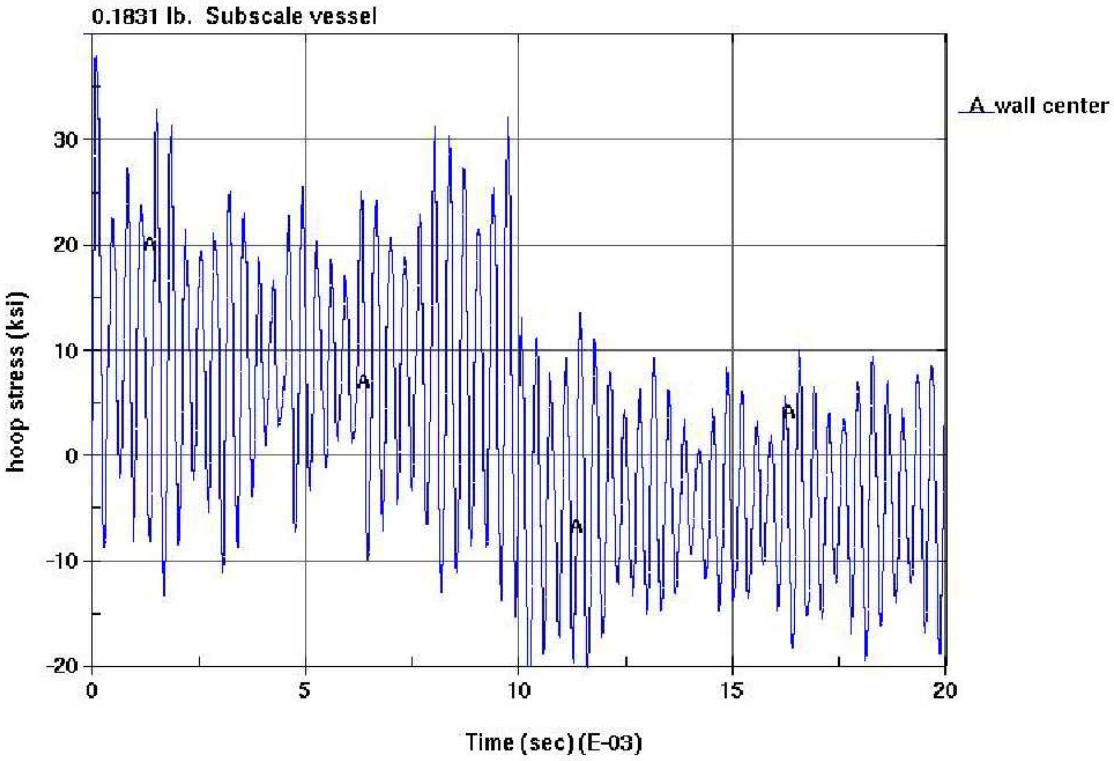


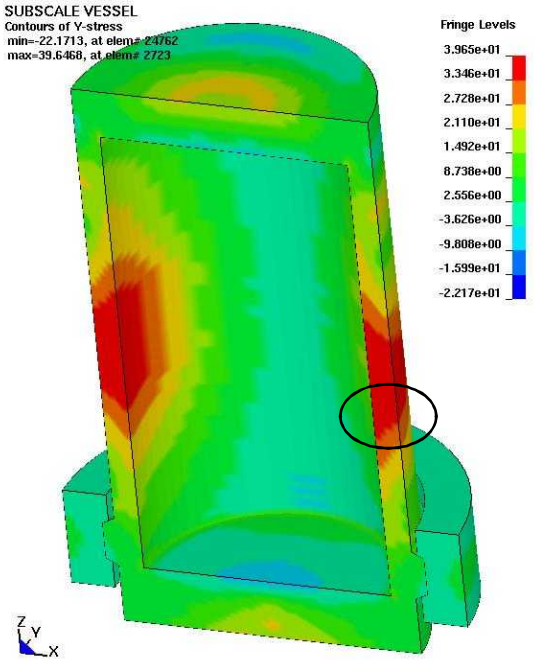


5x 0.6608 lb. detonations followed by
3x 0.2441 lb. detonations.

Fatigue and fracture analysis

Hoop stress at vessel wall

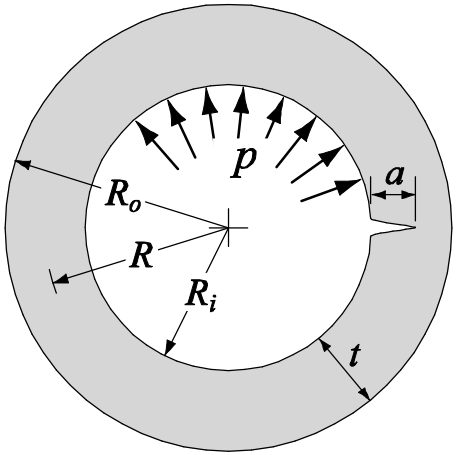




Each detonation event =
1 cycle at 38 ksi +
7 cycles at 33 ksi +
22 cycles at 25 ksi +
60 cycles at 10 ksi.

conservative

K_I equation for long part-through internal flaw



$$K_I = \frac{2pR_o^2}{R_o^2 - R_i^2}\sqrt{\pi a}\ F$$

$$F = 1.1 + A\left[4.951\left(\frac{a}{t}\right)^2 + 1.092\left(\frac{a}{t}\right)^4\right]$$

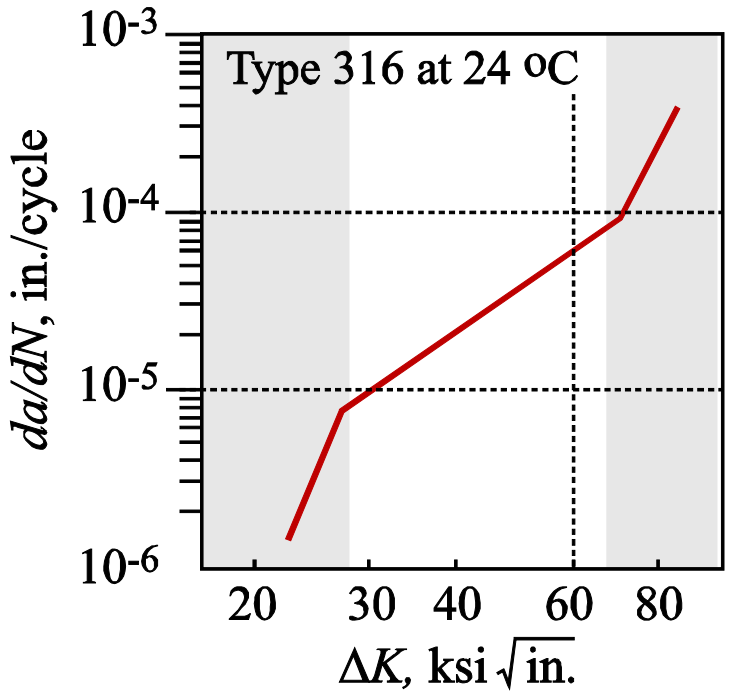
$$A = \left(0.125\frac{R_i}{t} - 0.25\right)^{0.25} \quad \text{for: } 5 \le \frac{R_i}{t} \le 10$$

$$A = \left(0.2\frac{R_i}{t} - 1.0\right)^{0.25} \quad \text{for: } 10 \le \frac{R_i}{t} \le 20$$

$$\frac{a}{t} \le 0.75$$

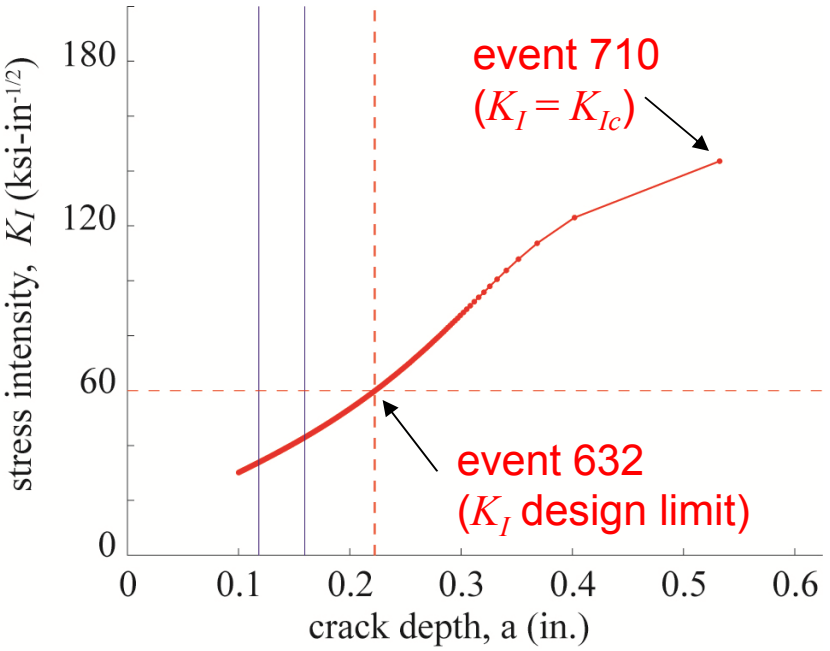
conservative

crack growth rate curve



conservative to use
K_I limit = 60 ksi-in$^{1/2}$

Stress intensity vs. crack depth



Each detonation event = 0.1831 lb.
Red dashed line: user defined K_I limit of 60 ksi-in$^{1/2}$
Blue lines: 250 detonation events

Conclusions

Membrane strains are prominent at vessel wall.
Bending strains are prominent at vessel ends.

At larger loads, vessel wall undergoes through-wall yielding while aft end maintains an elastic core.

Based on limits for plastic collapse, subscale vessel is rated to 0.1744 lb. TNT.

Based on strain design limits, subscale vessel is rated to 0.2441 lb. TNT (membrane strain limit).

At high load levels, failure mode is governed by plastic straining.

At lower load levels, failure may be cause by fatigue and fracture.
Vessel can withstand over 630 detonation events at 0.1831 lb. TNT.