The Blast Failure of Buncefield Fuel Storage Tanks T910 and T601

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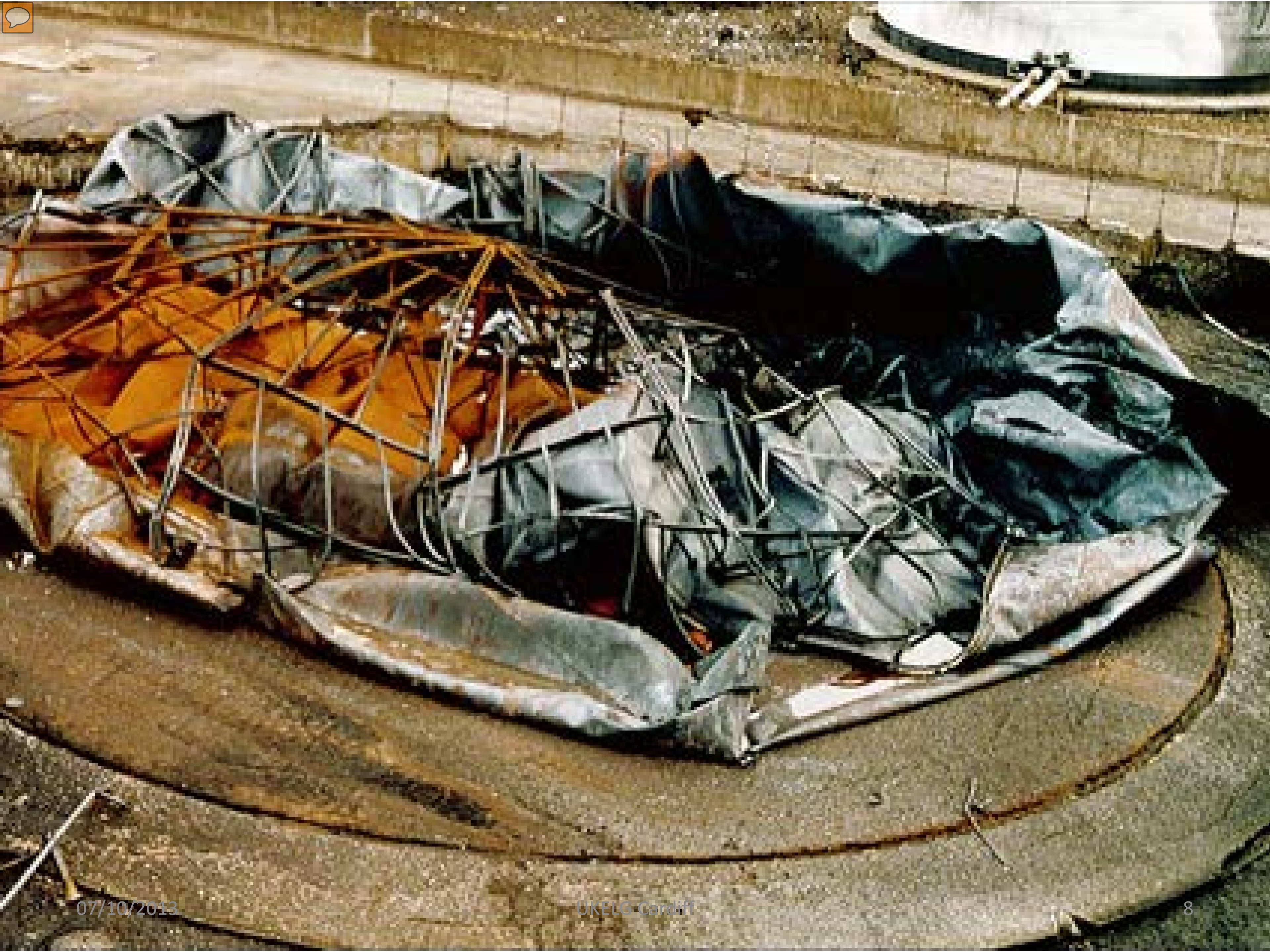
Outline

- Summary of tank blast damage
- Possible failure mechanism
- Attempts at Finite Element Modelling of blast damage – fluid/structure interactions
- Consequences as to blast development

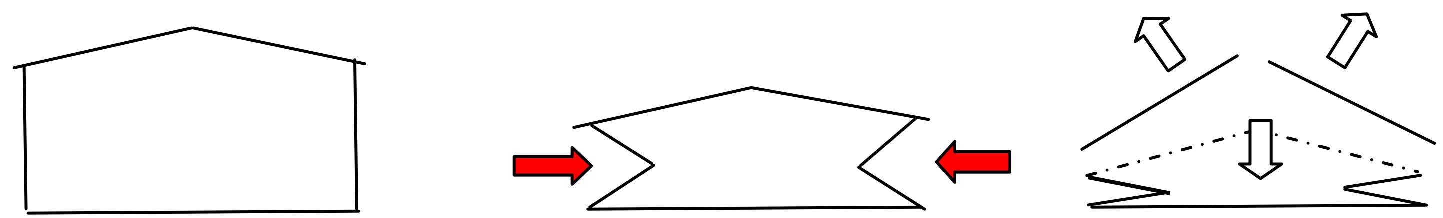
Event

- 06:01 am December 11, 2005, Buncefield UK
- Tank overfilling – over 300 tonnes winter-grade petrol released and formed vapour cloud
- Massive explosion – fire engulfed fuel tanks
- Extensive damage to vehicles included tyre de-beading and extreme crushing – detonation suspected
- Tank fires raged for several days


07/10/2013
UKELG Cardiff



Possible T910 failure mechanism?



a) b) c)

Crushing interaction of a positive blast shock front with an empty or partially empty roofed cylinder; e.g. T6, T910, T911, T914. Before: **a**) Blast crushing: **b**) Roof being blown off, walls and rafters collapsing; **c**).

FE models of transfer tanks

Geometry

Diameter: 6 m; Wall - height: 9.9 m, thickness: 6mm; Roof – diameter: 3.02m, pitch 1:5
Base thickness: 6mm, Roof thickness: 5mm
Angle iron around top: 75 mm by 75 mm by 4.8mm thick?

Mesh

S4 shell elements: A 4-node doubly curved general-purpose shell, finite membrane strains.
80 elements around circumference. Walls: 20 elements high
80 fasteners connect roof to angle iron; designed to fail in tension at about 15 kPa static overpressure.

Pneumatic air cavity (above fuel cavity)

Ambient pressure: 100kPa, Molec. weight: 0.0289 kg/mol; Specific heat 1005J/kg-K; Univ. gas const.: 8.314 J/K-mol Adiabatic model

Hydraulic fuel cavity (height 4.95 m)

A-1 jet fuel: Bulk modulus: 1.3E9 Pa, Density: 800 kg/m^3, Thermal expans. coeff.: 0.001/^{o}C

Surface membrane (to provide a boundary between the air and fuel cavities)

Polyethylene HDPE: Elastic - E: 0.8 GPa, Poisson's ratio: 0.4, Density: 950 kg/m^3
Assumed 2 mm thick to limit surface distortions

Positive blast pressure for 600 series tank

Peak pressure scaled to 1.51 MPa, propagation speed: 1675 m/s
2.05 ms delay from first to last loading panel (from 9^o to 99^o around circumf.)

FE models T910 Series Tanks

Geometry
Diameter: 25m, Wall - height: 14.33m, thicknesses: 10mm (3.62m), 8mm (3.62m), 6mm (7.09m)
Roof: 12.53m radius, pitch 1:5, 5 mm thick. Base: 5 mm thick.
Angle iron around top: 150mm by 150mm by 15mm thick
Wind girder at height: 8.3m, size: 121 mm wide, 71 mm high, 8 mm thick

Mesh
S4 shell elements: A 4-node doubly curved general-purpose shell, finite membrane strains.
80 elements around circumference. Walls: 20 elements high
80 fasteners connect roof to angle iron. Supposed to fail at about 15 kPa overpressure but do not.
Roof trusses and centre pole: B31 2-node beam elements

Pneumatic air cavity
Ambient pressure: 100kPa, Molec. weight: 0.0289 kg/mol; Specific heat 1005J/kg-K; Univ. gas const.: 8.314 J/K-mol Adiabatic model

Positive blast pressure for 900sries tank
Peak pressure scaled to 1.74 MPa, propagation speed: 1790 m/s
8.0 ms delay from first to last loading panel (from 9^o to 99^o around circumf.)

Steel properties

E: 210 GPa, Poisson's ratio: 0.3, density: 7800 kg/m^3
Johnson-Cook model of mild steel: A=217MPa, B=234MPa, n=0.643, m=0.807, C=0.076 for strain rates from 10^{-3}/s to 1800/s. Ref.: Vedantam et al., 2006
Ductile damage: fracture strain: 0.4, stress triaxiality: 0.8, strain rate: 1/s
Shear damage: K_s: 0.03, fracture strain: 0.4, shear stress ratio: 2.2, strain rate: 1/s
Damage evolution: displacement at failure: 0.1, exponential softening law parameter: 10

Loadings

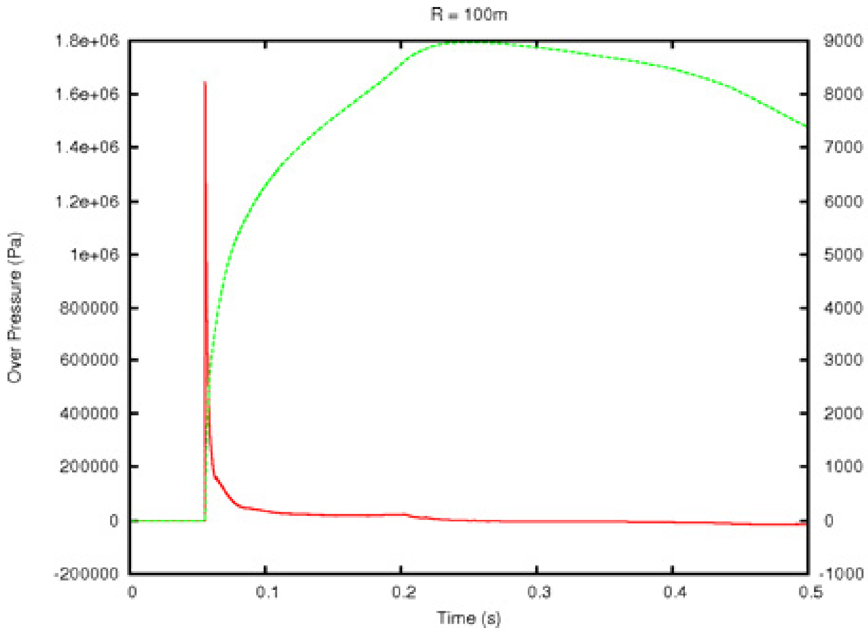
Gravity loading
Gravity is ramped up over first 0.05s. Blast load then applied.

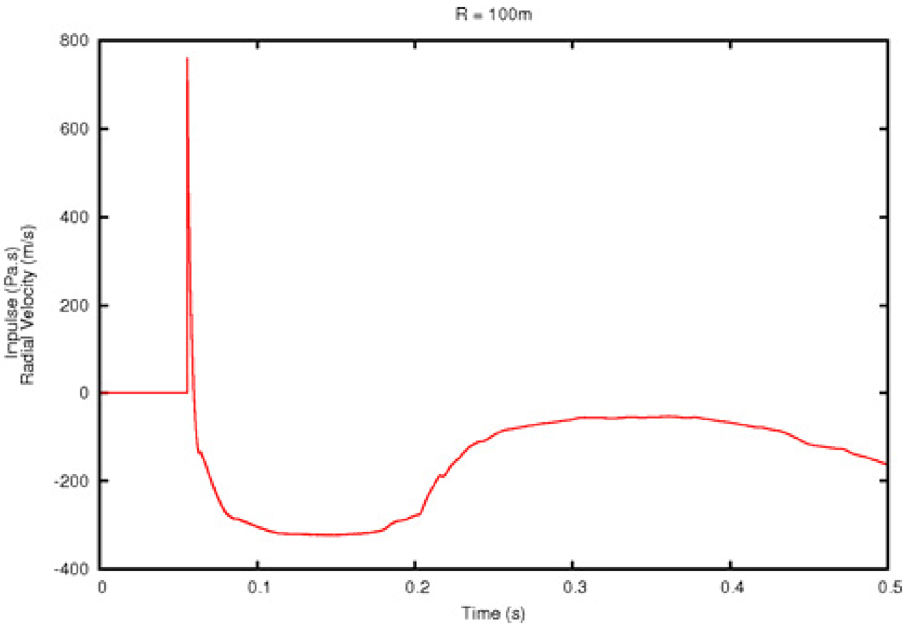
Positive pressure pulse
Acts along neg. X axis.
Pos. air pressure history as per Fig. H.6 (left-side) of r718 report (peak 1.65 MPa).
Actual pressure values scaled slightly depending on nature of local vapour cloud.
Time histories applied in 18^o sectors with delays based on propagation speed.
Smoothly distributed pressure over 216^o of front (pos. X) surface, decreasing as cosine function similar to ref. Duong et al., 2012, Part I.
For full-scale loading, the entire pressure is scaled by factor of 2 to represent reflected pressure, gradually decreasing to zero over the 216^o loading zone.

Negative drag force
Neg. drag air velocity history as per Fig. H.6 (right-side) of r718 report (peak -325 m/s)
Starts at 5.4 ms and ends at 212 ms (loading time)
Smoothly distributed over 180^o of rear (neg. X) surface (decreasing cosine function)
Parallel force vectors act in pos. X-direction

Pressure and radial velocity loading

- Pressure
- Radial velocity



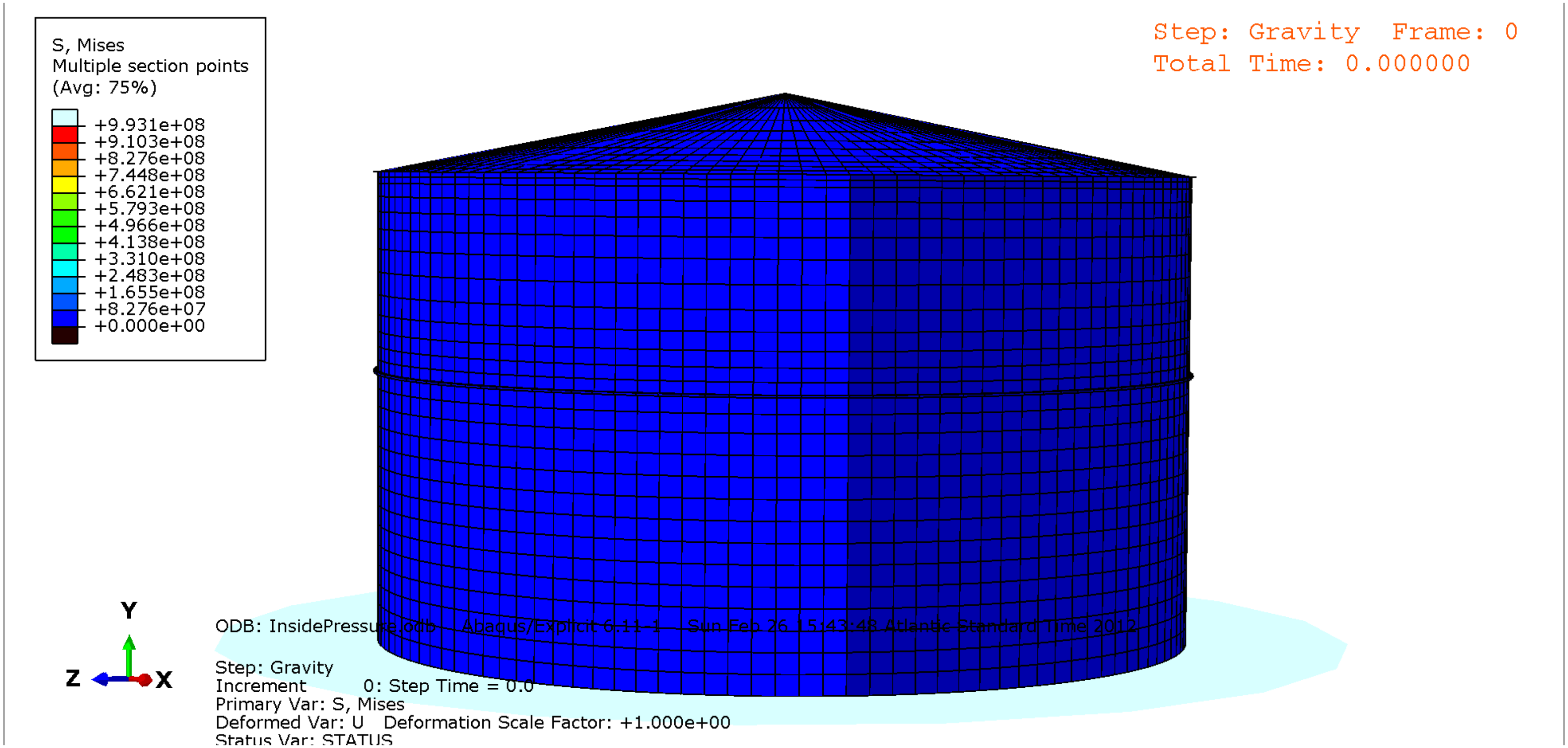


Simulation details

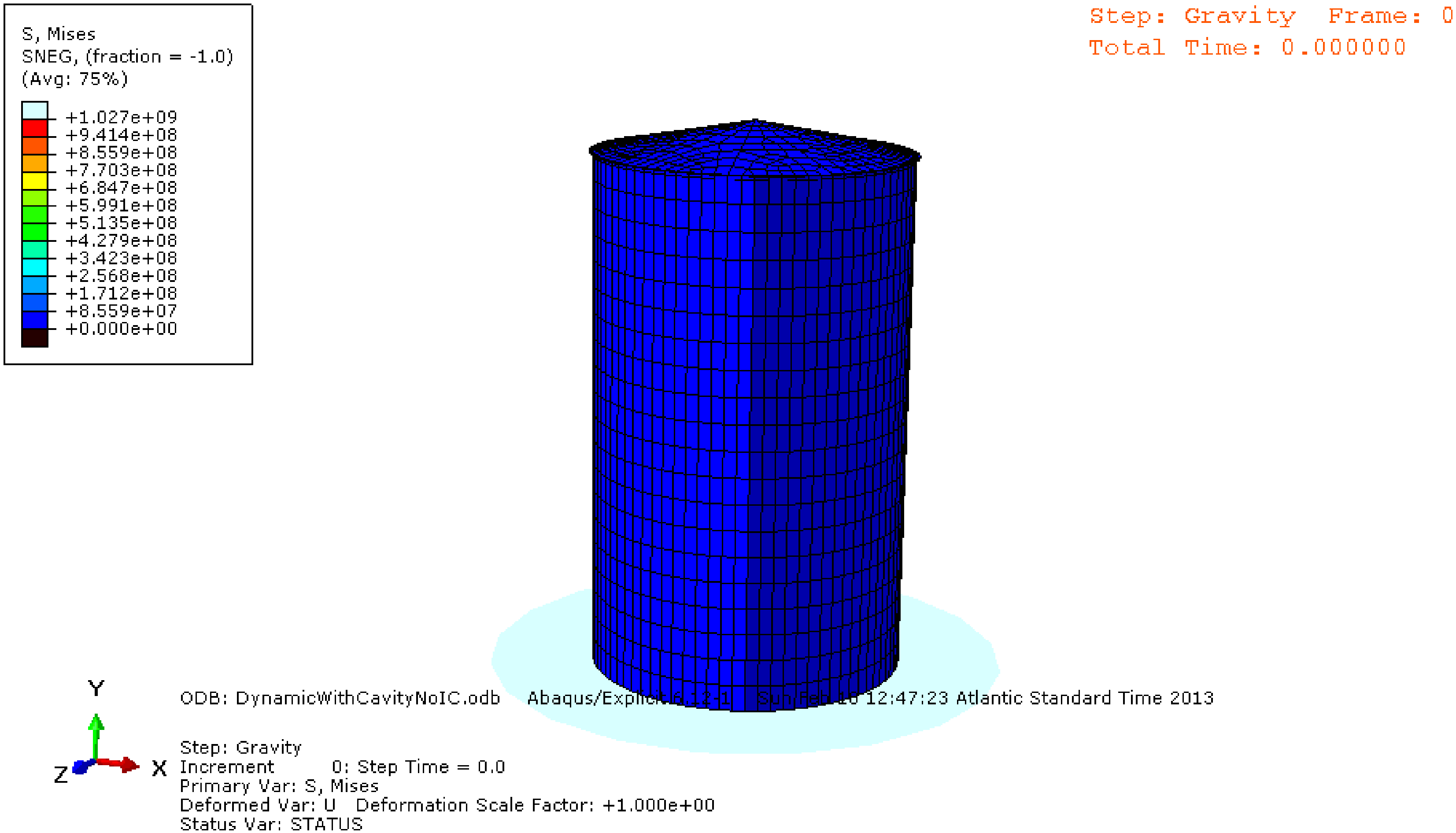
Abaqus Explicit version 6.12-1 solver with non-linear functions
General contact, including self contact, with coeff. friction: 0.5
Fixed rigid base for steel tank bottom to contact
Tank bottoms have rough friction contact (no slipping but lift off capability)

Air cavity failure

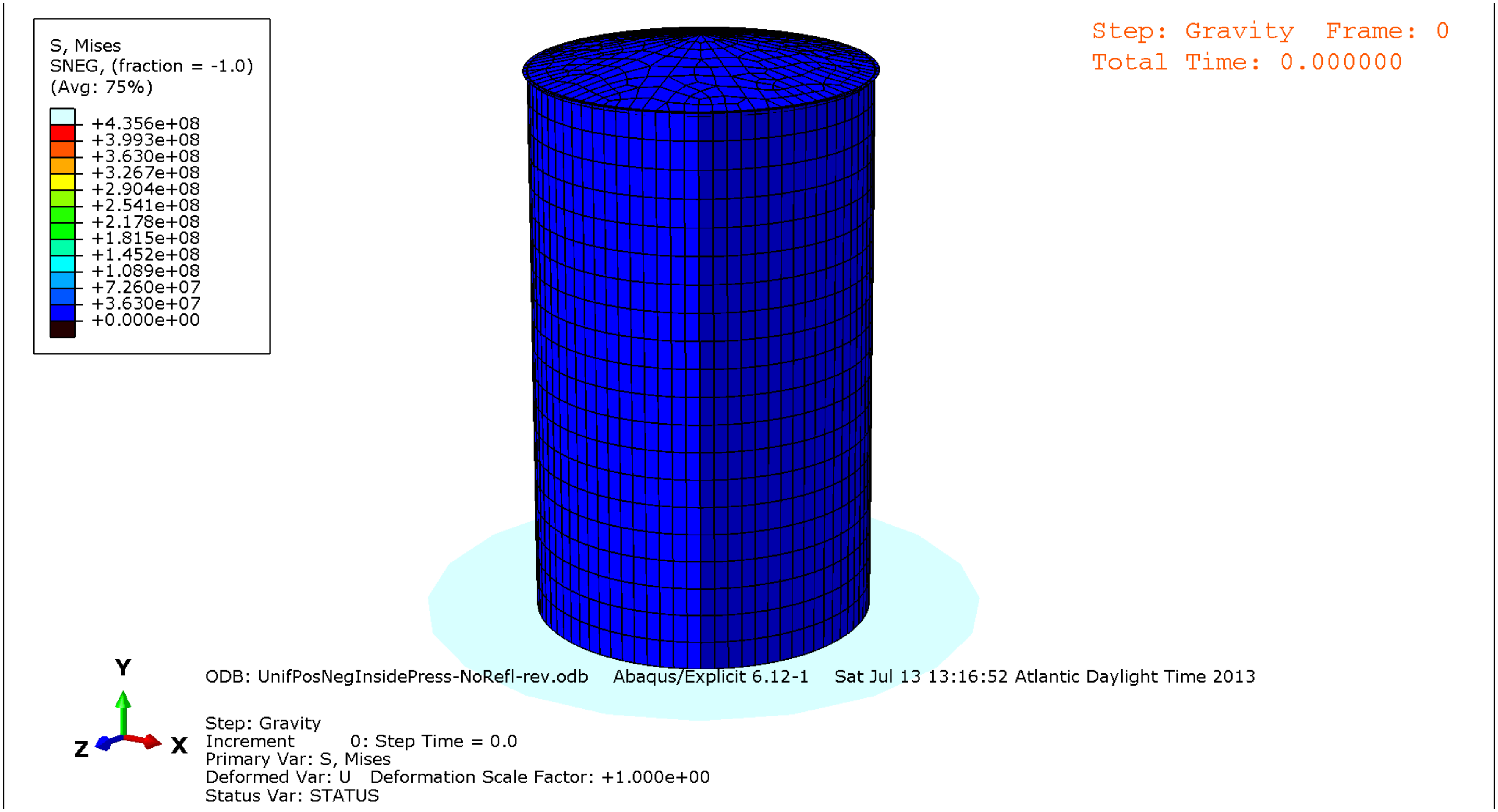
Solution stops when air cavity has huge (unrealistic) openings in surface.
A more reasonable air cavity pressure is manually estimated when cavity opening is smaller.
This pressure is then used as air cavity internal pressure in a second solution run.


S, Mises
Multiple section points
(Avg: 75%)
+9.931e+08
+9.103e+08
+8.276e+08
+7.448e+08
+6.621e+08
+5.793e+08
+4.966e+08
+4.138e+08
+3.310e+08
+2.483e+08
+1.655e+08
+8.276e+07
+0.000e+00
Step: Gravity Frame: 0
Total Time: 0.000000
Y
Z
X
ODB: InsidePressure.odb Abaqus/Explicit 6.11-1 Sun Feb 26 15:43:48 Atlantic Standard Time 2012
Step: Gravity
Increment 0: Step Time = 0.0
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.000e+00
Status Var: STATUS

Empty 600 series tank positive blast phase



Half full 600 series tank positive and negative blast loading



Conclusions

- Preliminary blast wave interaction/damage of Buncefield fuel storage tanks attempted
- Blast damage, analyses and observations, consistent with a blast wave moving west to east.
- Blast damage, analysis and observations, consistent with a detonation.

Future work

- Bund walls afford blast protection to tank bases?
- Incorporation of fluid-structure interactions.
- Further examination of tank-top failure release strengths.
- Further examination of blast wave and grid dependence.