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Pressure Spike in the LBNF Absorber Core's Gun Drilled Cooling Channel From an Accident Beam Pulse

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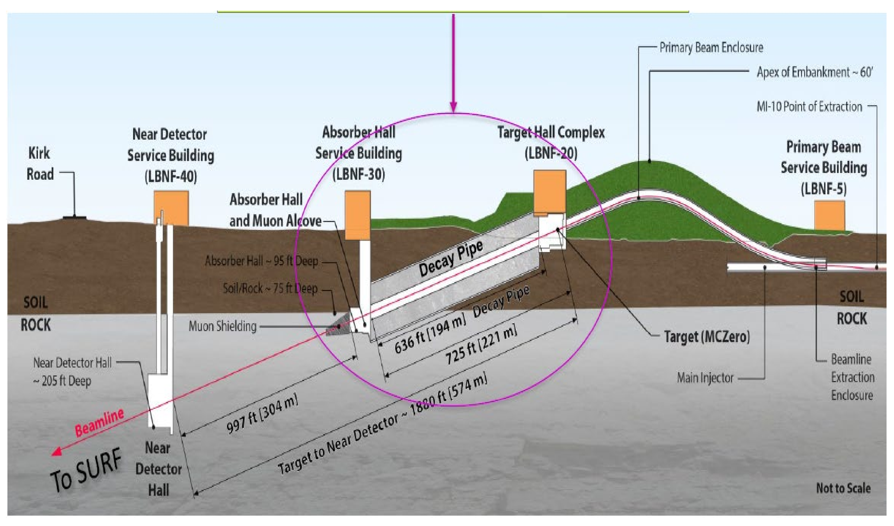
Abstract

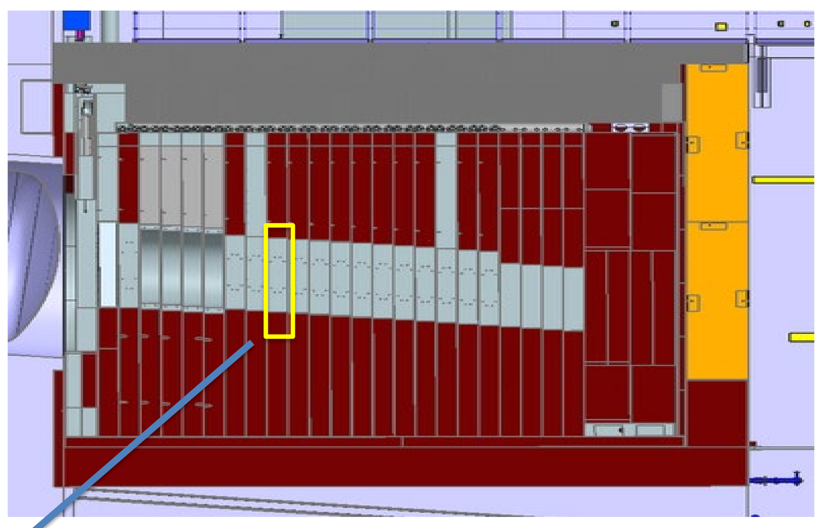
The LBNF absorber consists of thirteen 6061-T6 aluminum core blocks. The core blocks are water cooled with de-ionized (DI) water which becomes radioactive during beam operations. The cooling water flows through gun-drilled channels in the core blocks. The cooling water is supplied by the LBNF absorber radioactive water (RAW) cooling system which is designed as per ASME B31.3 normal fluid service. An uninhibited beam accident pulse striking the water channels was identified as a credible accident scenario. In this study, it is assumed that the beam pulse hits the absorber directly without interacting with any of the other upstream beamline components. The beam parameters used for the LBNF beam are 120 GeV, 2.4 MW with a 1.2 s cycle time. The accident pulse lasts for 10 µs. The maximum energy is deposited in the 3rd aluminum core block. For the sake of simplicity, it is assumed that the accident pulse strikes the 1 in. ID water channel directly. The analysis here simulates the pressure rise in the water during and after the beam pulse and its effects on the aluminum piping components that deliver water to the core blocks. The weld strengths as determined by the Load and Resistance Factor Design (LRDF) and the Allowable Strength Design (ASD) are compared to the forces generated in the weld owing to the pressure spike. A transient structural analysis was used to determine the equivalent membrane, peak, and bending stresses and they were compared to allowable limits.

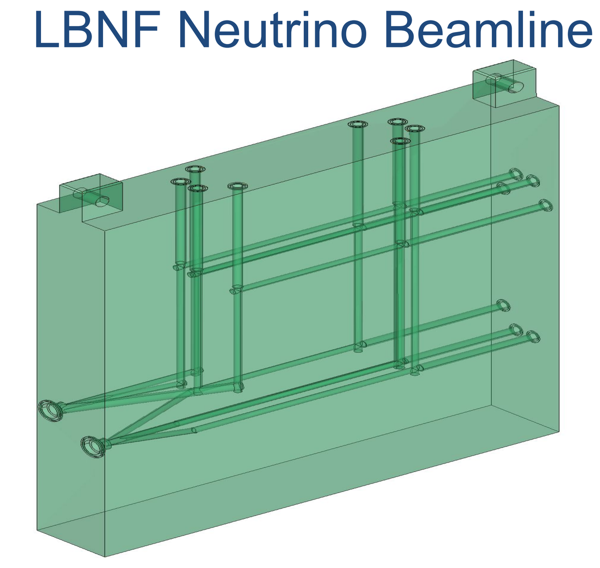
Overview

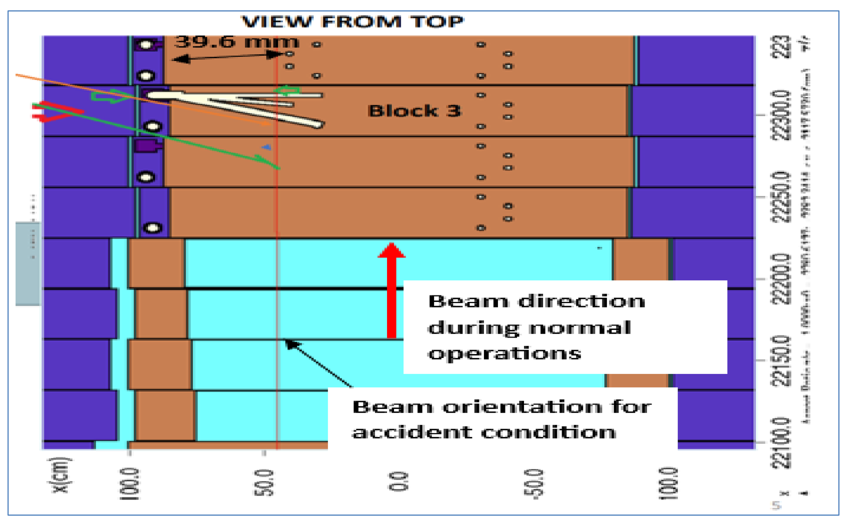
- The absorber consists of two major sections: The core and the surrounding concrete and steel shielding.
- The core consists of an aluminum spoiler block to initiate the particle shower, four aluminum mask blocks with air space in the center, thirteen aluminum core blocks, and four steel blocks.
- During the uninhibited accident condition, maximum energy is deposited into 3rd aluminum core block.
- The energy deposition data is a gaussian distribution with a peak value of 72 J/cm^3 per pulse with an rms width of 20 mm.



LBNF Neutrino Beamline


Absorber Cross Section

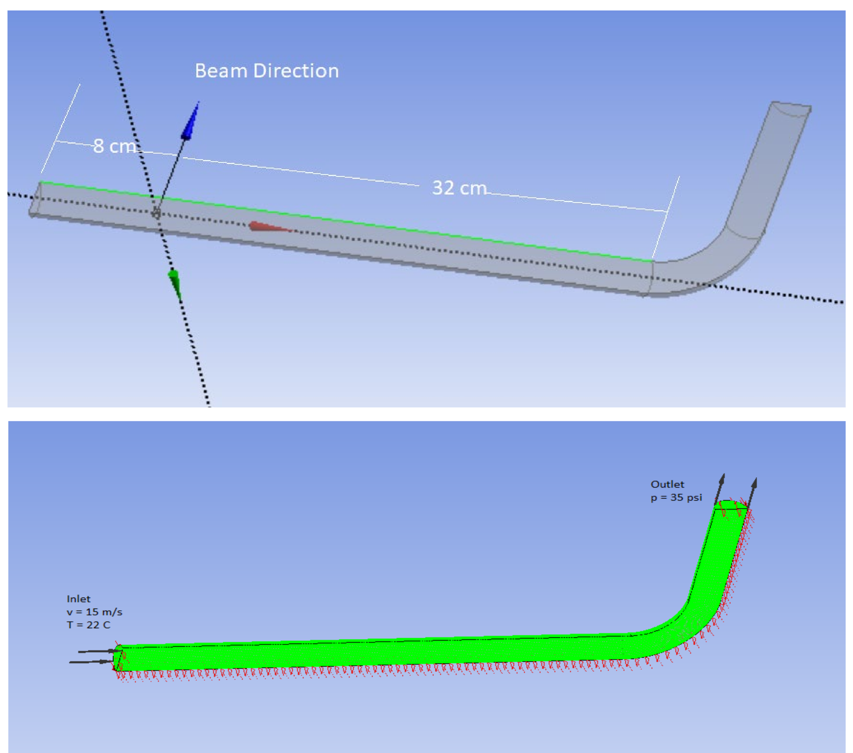

Absorber Core Block



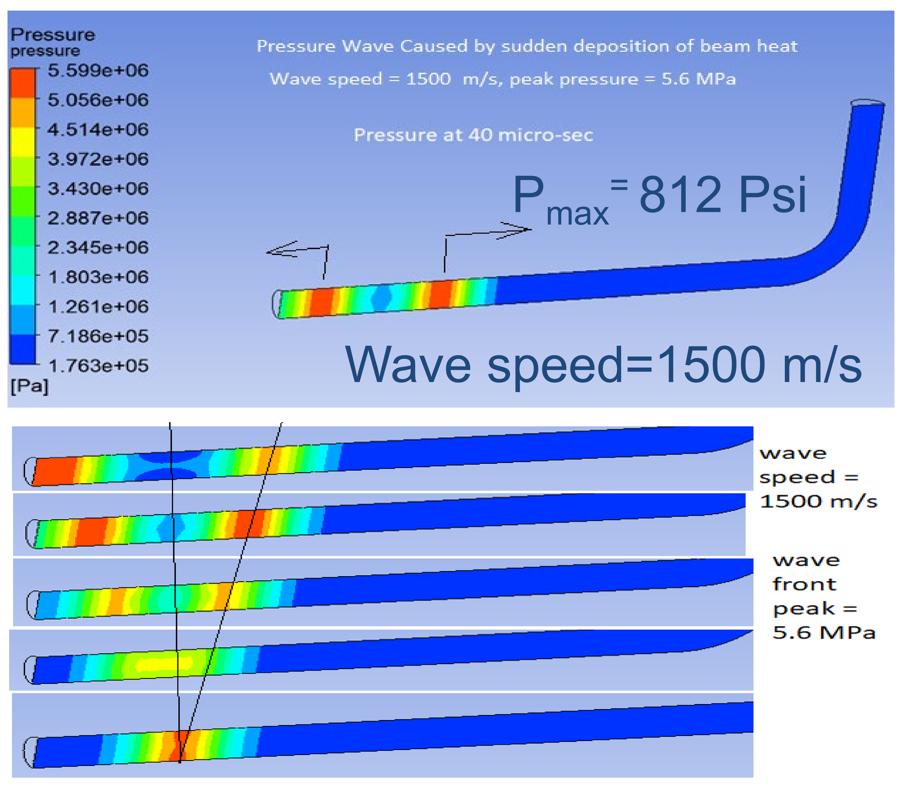
Accident Beam Orientation

Pressure Spike in Water Channel

- MARS15 software package is used to simulate beam interactions with material and energy deposition.
- The energy deposition data is used as an input to a transient Computational Fluid Dynamics (CFD) simulation to determine the peak pressure generated in the 1 in. water channel.
- The initial water temperature, velocity, and pressure in the tube were assumed to be 22 ^oC, 15 m/s and 35 Psi, respectively.
- The pressure wave caused by the sudden deposition of heat was 5.6 MPa (812 Psi).
- The wave speed was simulated to be approximately 1500 m/s.



Geometry and Boundary Conditions



Pressure Spike

Effect of Pressure Spike on Aluminum Parts

- The effect of the pressure spike is determined on the closest weld present on the core block.
- This weld connects the cooling supply line to the 6061-T6 aluminum core block.
- The Aluminum Design Manual is used to determine the strength of the weld and the base metal using the Load and Resistance Factor Design (LRFD) and Allowable strength Design (ASD) methods. The weld strength is also determined from ASME BPVC VIII, Div I.

$$R_{nb} = 0.6F_{tuw}S_wL_{we}$$

$$S_wL_{we} = 0.707a\pi D$$

$$R_{nw} = 0.51F_{tuw}S_wL_{we}$$

$$R_{nb}[LRFD] = \emptyset R_{nb}$$

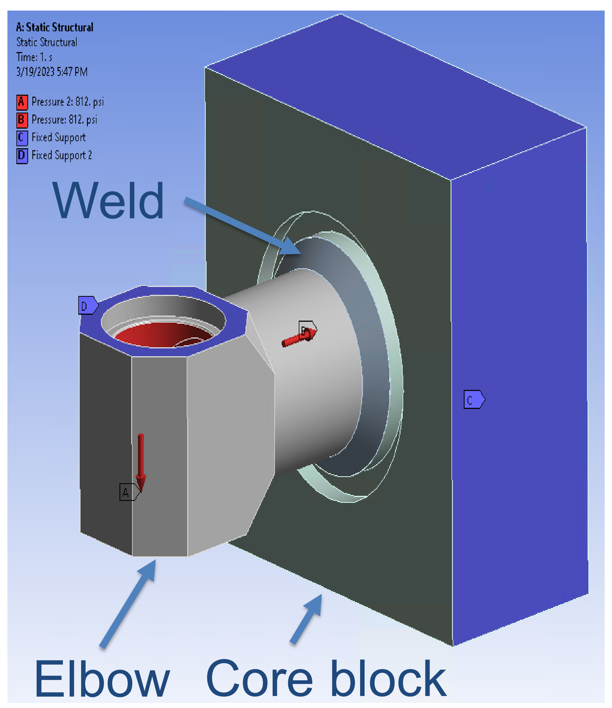
$$R_{nb}[ASD] = \frac{R_{nb}}{\Omega}$$

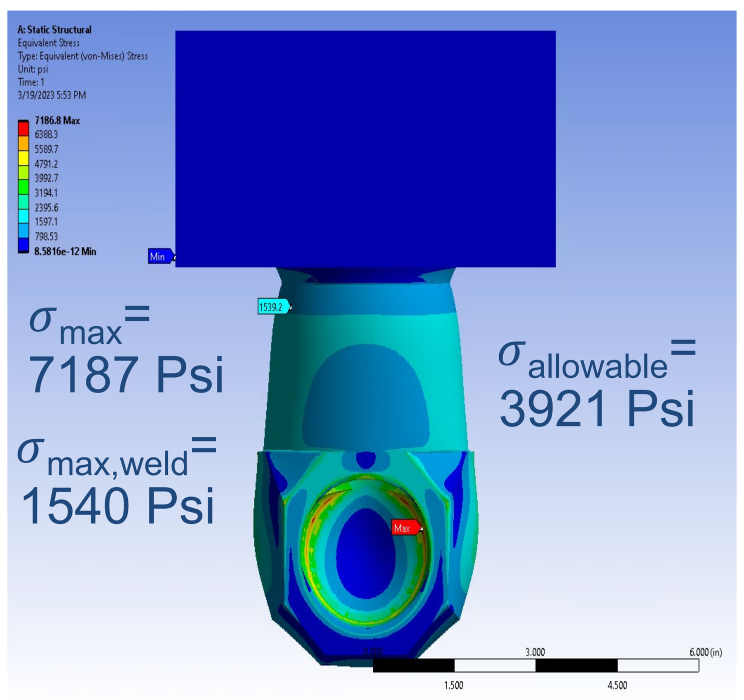
$$R_{nw}[LRFD] = \emptyset R_{nw}$$

$$R_{nw}[ASD] = \frac{R_{nw}}{\Omega}$$

$$F_{MAWL} = 0.49S_wL_{we}S$$

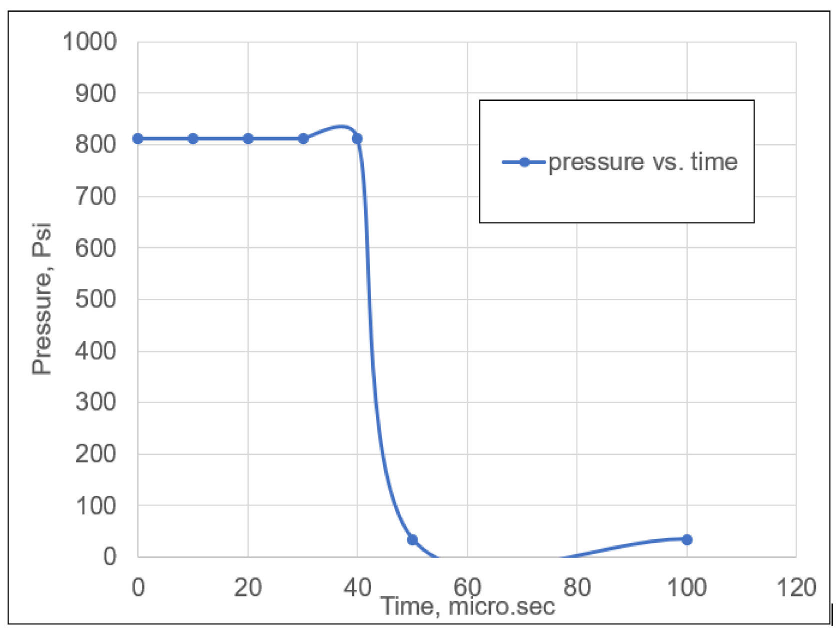
Parameter	*Value*
Base metal strength per LRFD	24737 lb
Base metal strength per ASD	16914 lb
Weld metal strength per LRFD	21026 lb
Weld metal strength per ASD	14377 lb
Fillet weld strength per BPVC VIII, Div I	8979 lb



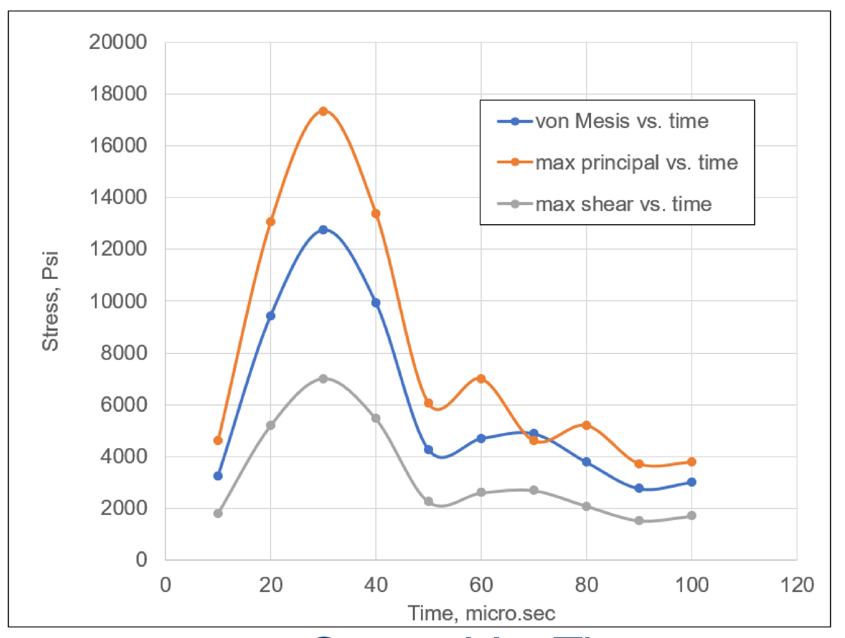


Transient Analysis

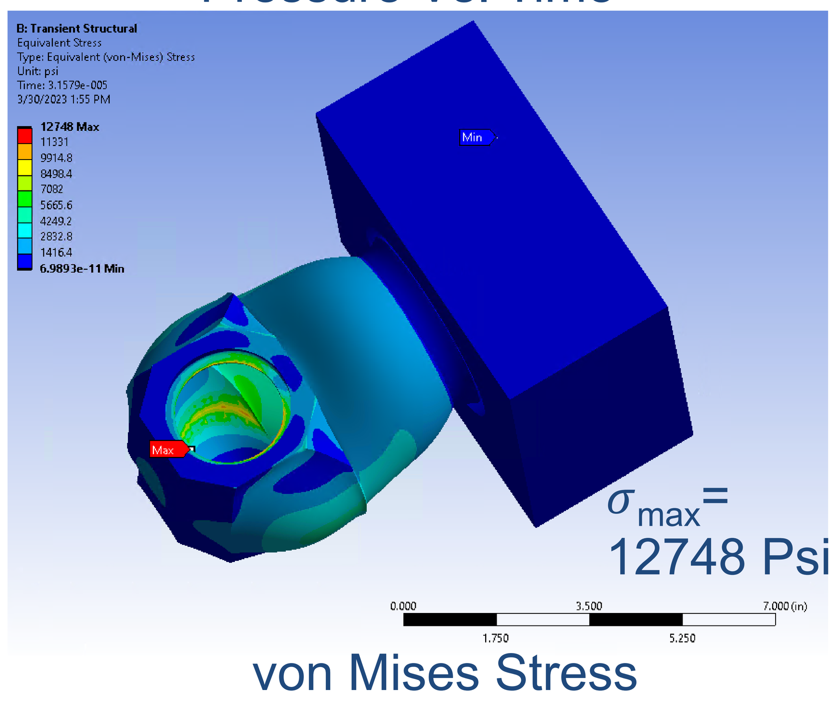
- A transient structural simulation is performed on the elbow-core block assembly.
- A pressure input with respect to time is applied on the surfaces that will be subjected to pressure spike. The resultant von Mises, principal, and max shear stresses are simulated.
- The stress analysis is done as per ASME BPVC VIII, Div II Design by Analysis section.
- Membrane and bending stress along the Stress Classification Line (SCL) are determined.
- The summation of membrane and bending stresses are compared to the allowable limits of the 6061-T6 material listed in ASME BPVC II D, Table 2B, which is equal to 21,000 Psi.



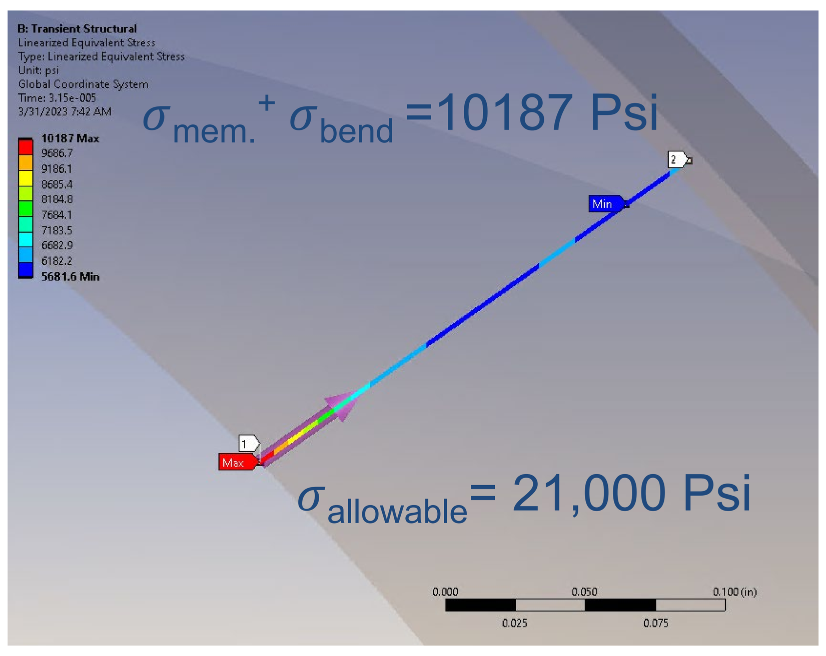
Pressure Vs. Time



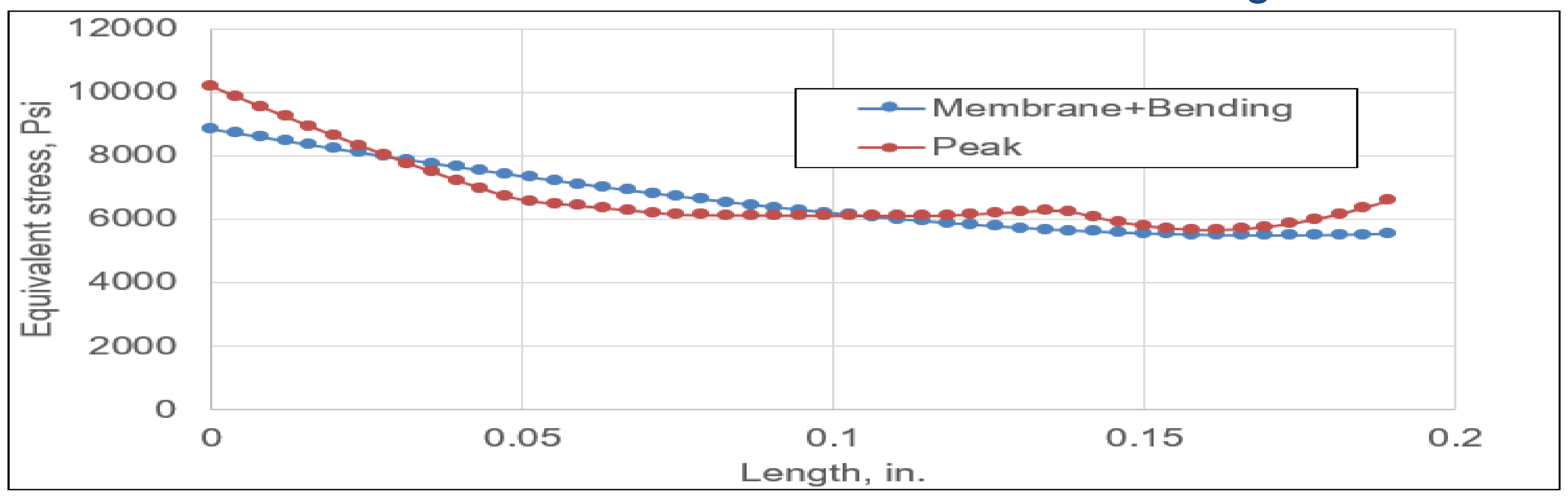
Stress Vs. Time



von Mises Stress



Stress Along SCL



Membrane and Bending Stress

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