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Quantification of Aluminum Increase Factors for Curtain Wall Design Using Finite Element Methods

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Our structural analysis of an aluminum-backed curtain wall system informs blast-resistant structural design practice

- Analysis focuses on the expected material response of an aluminum curtain wall support
- Blast loadings are typical of U.S. government criteria for domestic projects
- Dynamic experiment test results of aluminum samples coupled to a three-dimensional finite element hydrocode account for: over-strength, dynamic strengthening, and post-failure response of aluminum

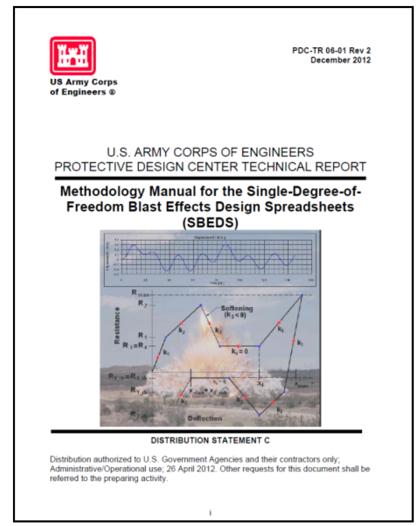
The additional fidelity of our material representation eliminates the need to upgrade the structural member

The minimum construction requirements for curtain wall do not allow meaningful increase factors

- Guidance for the design of façade systems governed by the "Authority Having Jurisdiction" per ASCE's "Blast Protection of Buildings" ASCE/SEI 59-11 (USACE for GSA and DoD)

Table 6-2: PDC-TR 06-01. *Single Degree of Freedom Blast Design Spreadsheets.* USACE PDC Technical Report. 05 October 2006.

Type of Aluminum	Yield Strength [MPa]	Strength Increase Factor (SIF)	Dynamic Increase Factor (DIF)
6061-T6	241 (35 ksi)	1.07	1.02
6063-T5	110 (16 ksi)	1.16	1.02
6063-T6	172 (25 ksi)	1.12	1.02


US Army Corps of Engineers ®

PDC-TR 06-01 Rev 2
December 2012

U.S. ARMY CORPS OF ENGINEERS
PROTECTIVE DESIGN CENTER TECHNICAL REPORT

Methodology Manual for the Single-Degree-of-Freedom Blast Effects Design Spreadsheets (SBEDS)

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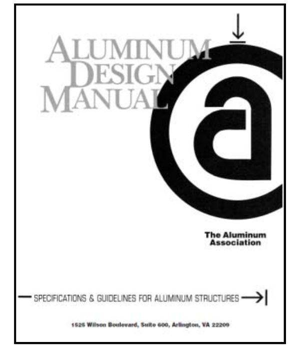
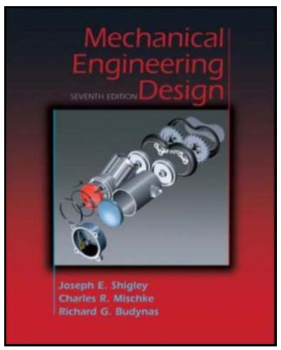
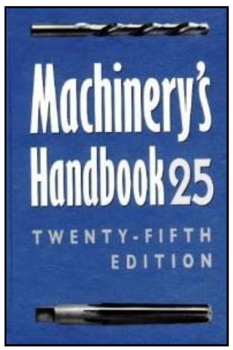
We believe these requirements are too conservative.
They result in systems with residual capacity (over what is required for the level of protection) and increased construction costs.

The literature confirms that the Strength Increase Factor (SIF) for Aluminum 6063-T6 is low

Aluminum Design Manual provides allowable yield strength (aluminum alloy 6063-T6) of σ_y=25 ksi with Equivalent Plastic Strain (EPS) at failure 0.057 (5.7%).





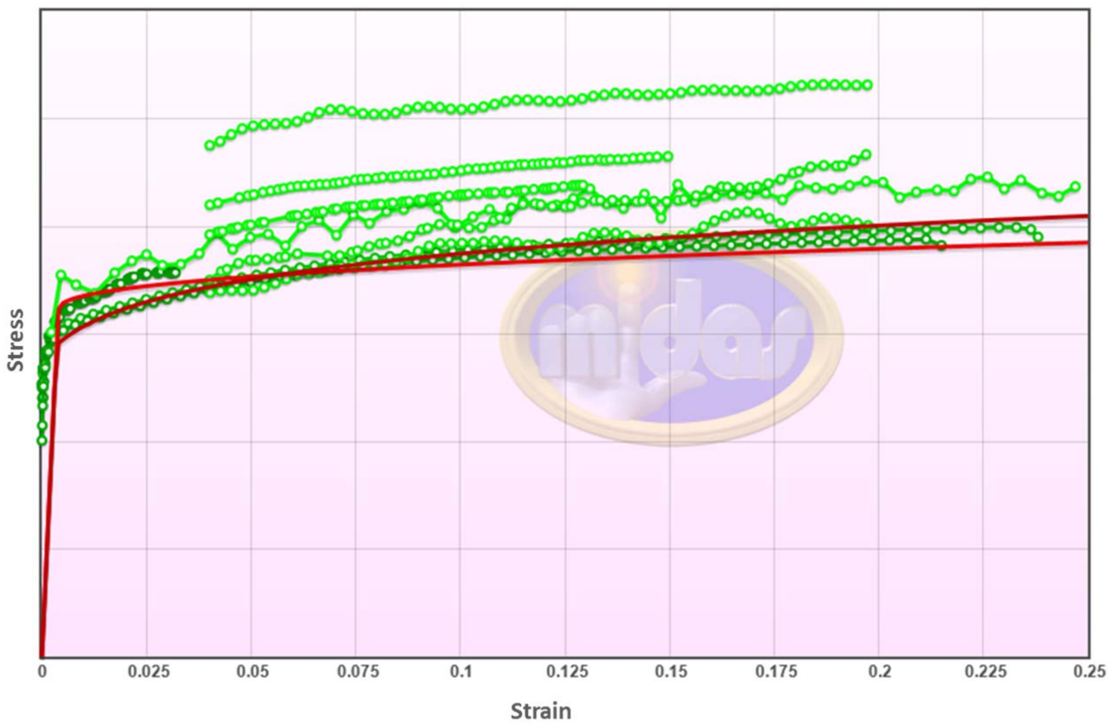


Analysis handbooks provide yield strengths of aluminum 6063-T6 alloy ~30-31 ksi.

Literature review shows yield strength of 30.1-30.3 ksi and fracture strains are 0.0945-0.1149 (9.4-11.5%).

These higher yield strengths support an increase in the SIF from 1.12 to 1.2

Dynamic aluminum test data shows the strain-rate dependence of aluminum and supports higher DIFs



Red solid lines are constitutive models:

- Steinberg-Guinan
- Johnson-Cook

Green open circles are experimental data for a range of strain-rates:

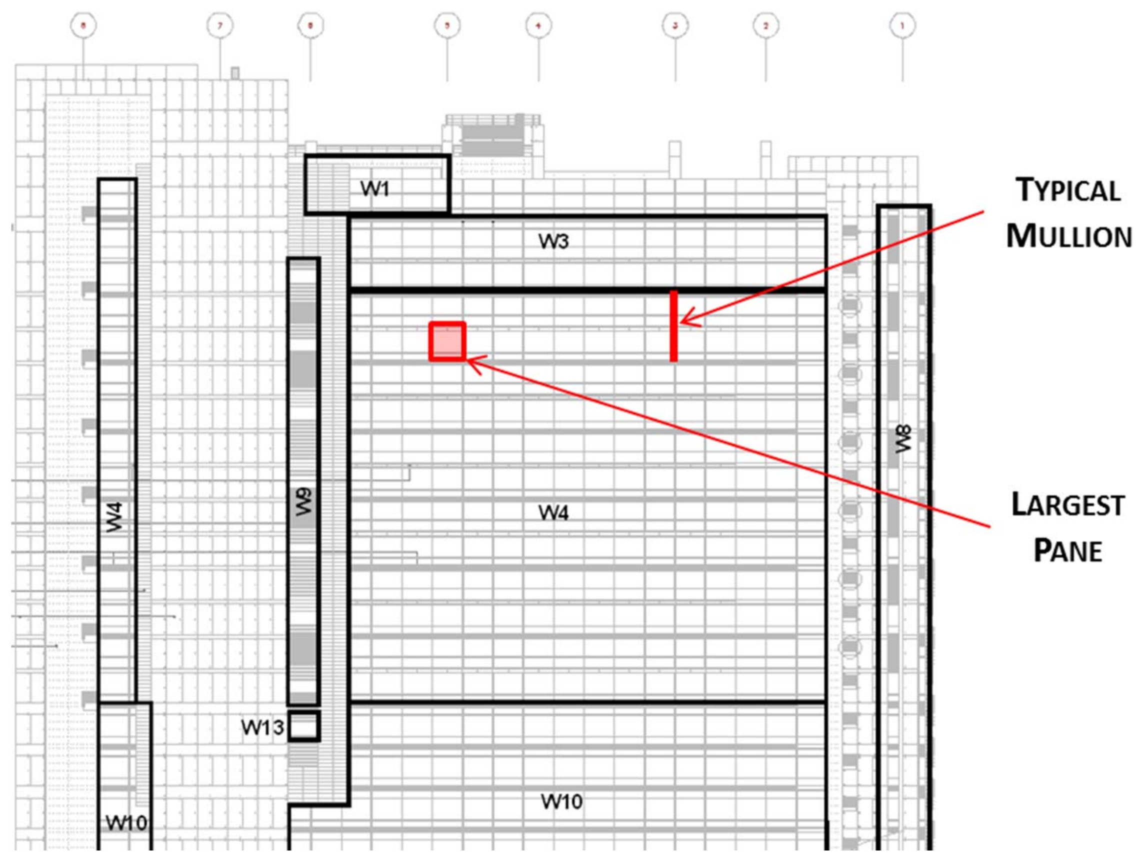
- 1e-9 μs^{-1} (0.001 s^{-1}) to 0.0048 μs^{-1} (4800 s^{-1})
- UFC 3-340-02 provides 0.1-0.3 s^{-1} (~10^{-7} μs^{-1}) for flexural members
- Our study showed 4 s^{-1} to 76 s^{-1}

Higher yield strengths at faster loading support an increase in the Dynamic Increase Factor (DIF) from 1.02 to 1.12

Analysis of a long-span aluminum curtain wall system was performed to quantify the effects of material strength increases

Aluminum-backed curtain wall system:

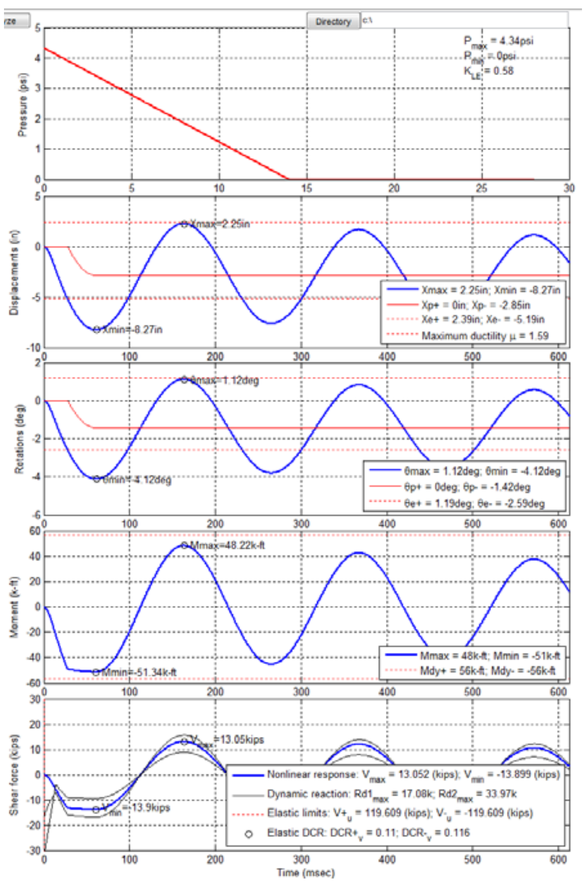
- 10”x3”x3/8” aluminum mullion extruded from 6063-T6 aluminum
- typical glass pane has a 9.75’ tributary width, 25.5’ span
- fix-pin end conditions
- Insulating Glazing Unit (IGU) with inner-pane lay-up of heat strengthened glass with inter-PVB layer
- Both High Load and Low Load for blast boundary condition



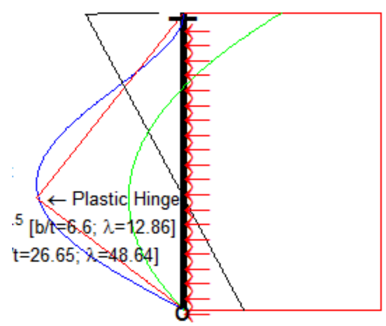
This system has a span longer than is typical.

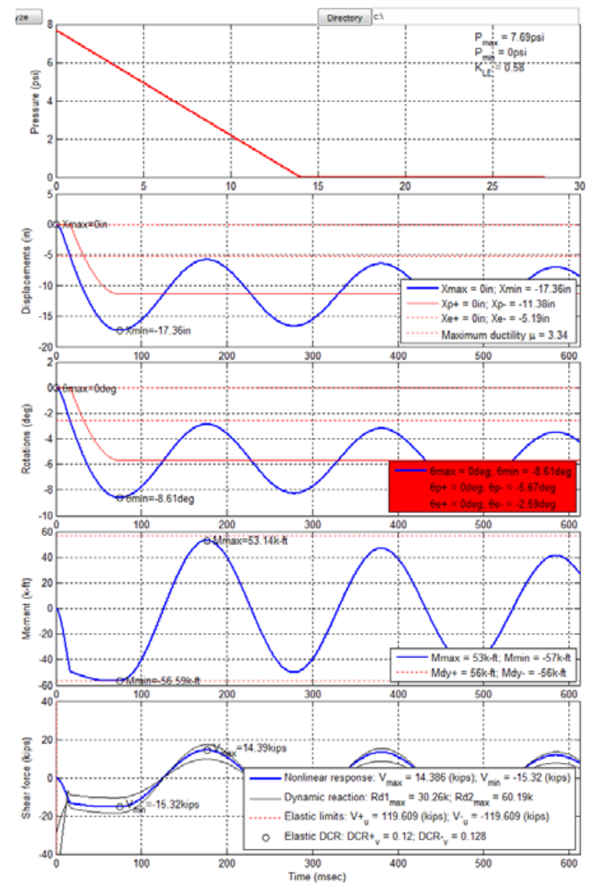
Results from Single Degree of Freedom (SDOF) analysis show that mullion performance is marginal

Passes under the Low Load (Design Load) and criteria

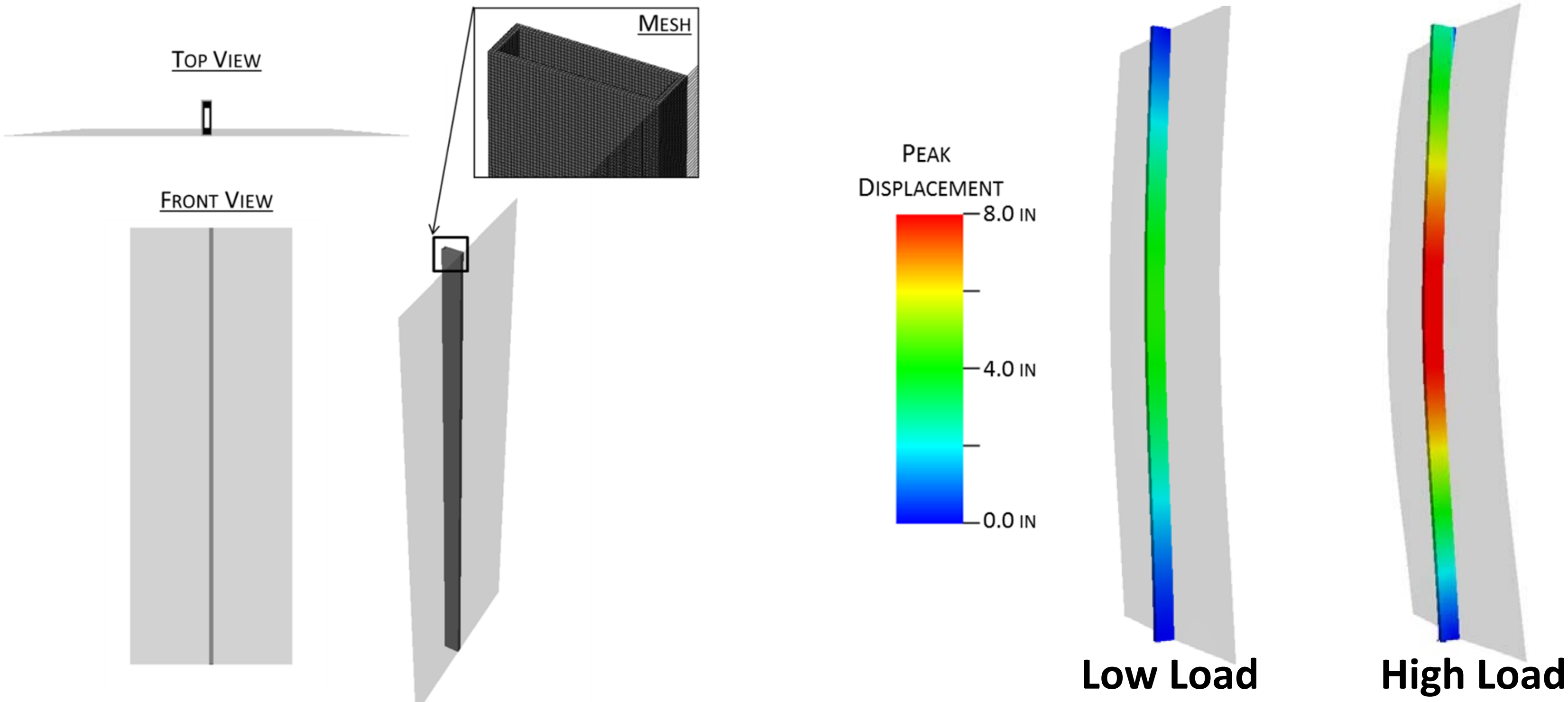


Fails under the High Load (Balanced Load) and criteria





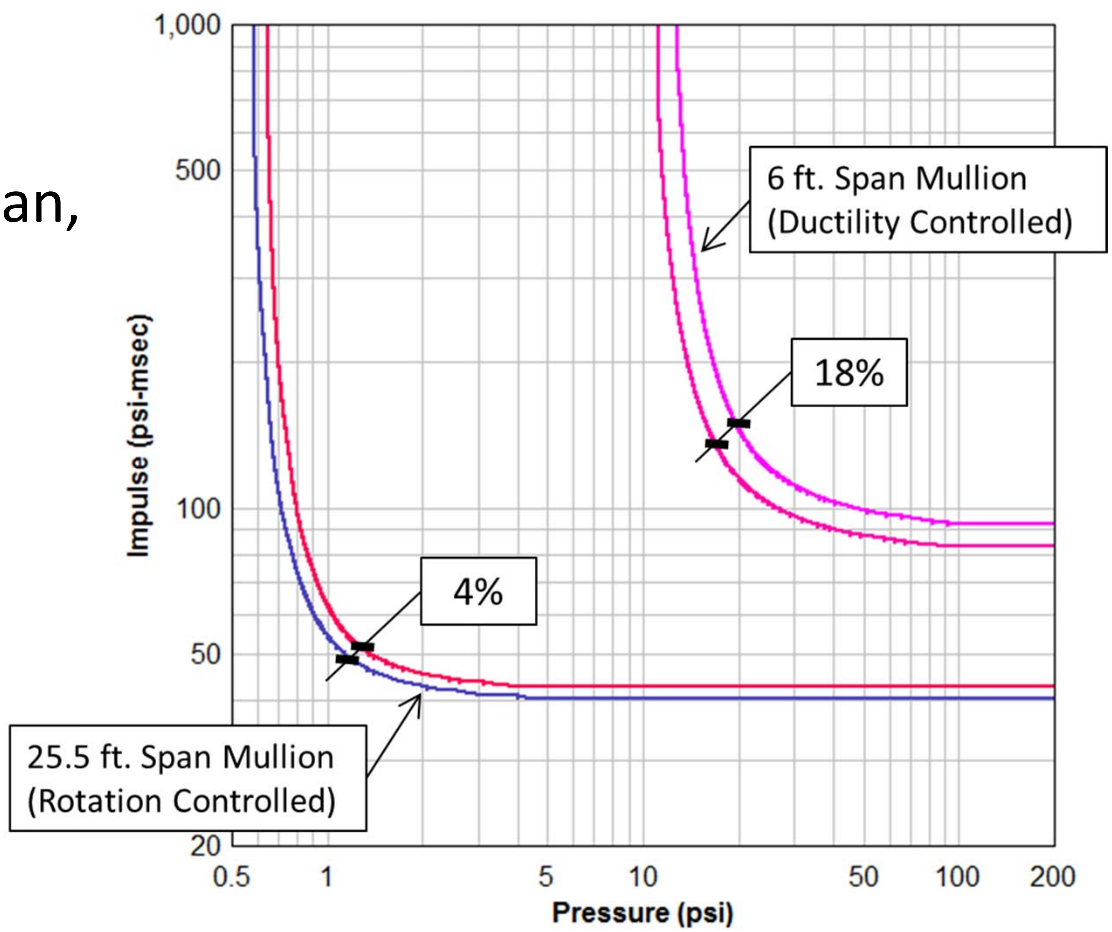
Finite Element Analysis (FEA) shows that the yield strength is exceeded, but there is little plasticity. The mullion is not expected to fail.



	Finite Element Analysis (FEA)		Single Degree of Freedom (SDOF)		
	Equivalent Plastic Strain* [%]	Peak Strain Rate [s^{-1}]	Deflection [in]	Ductility	Rotation
Low Load	0.3	4.3	7.5	1.5	3.8°
High Load	0.4	75.7	15.6	3.2	7.7°
* Dynamic fracture strain: 9.4-11.5%					

Recommend unlocking residual capacity by raising the SIF to 1.2 and the DIF to 1.12 for a yield strength of up to 34% higher than the prescribed design strength

- Rotation controlled, long-span, curtainwall systems (>20’) show a 4% improvement in performance
- Ductility controlled, ribbon curtainwall systems (~6-8’) show an 18% improvement



This study can be applied to any material with dynamic test data!

Questions?