SEM XIII International Congress on Experimental and Applied Mechanics
Orlando, FL, June 6-9, 2016
SAND2016-5237C

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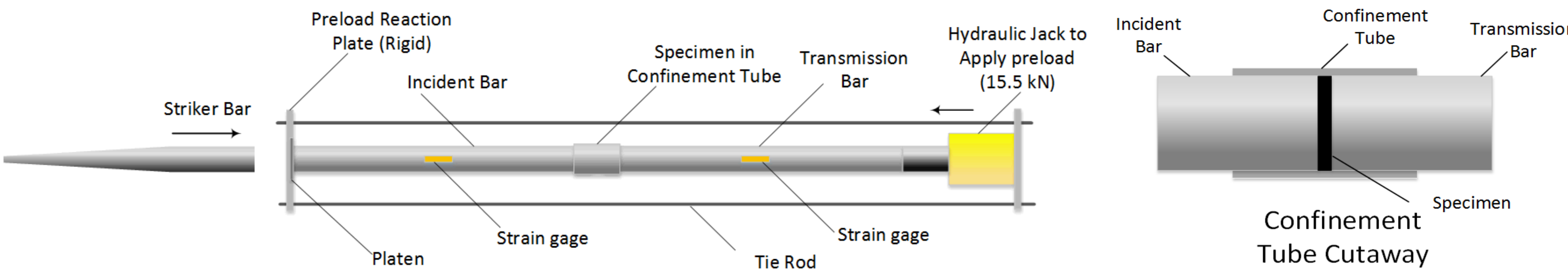

Low-Pass Mechanical Filter Evaluation Using Frequency-Based Kolsky Bar Analysis

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U.S. DEPARTMENT OF ENERGY
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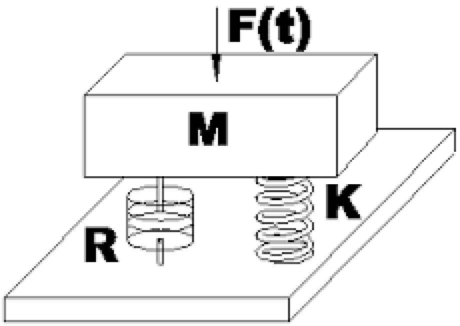
Shock Isolation/Mitigation

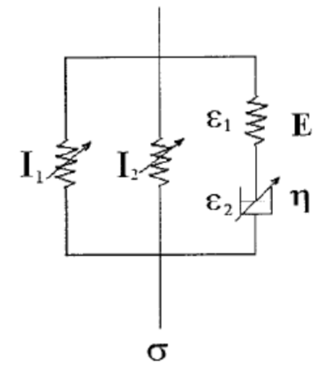
- Purpose: to isolate an object from shock impact
  - Survivability
  - Functionality

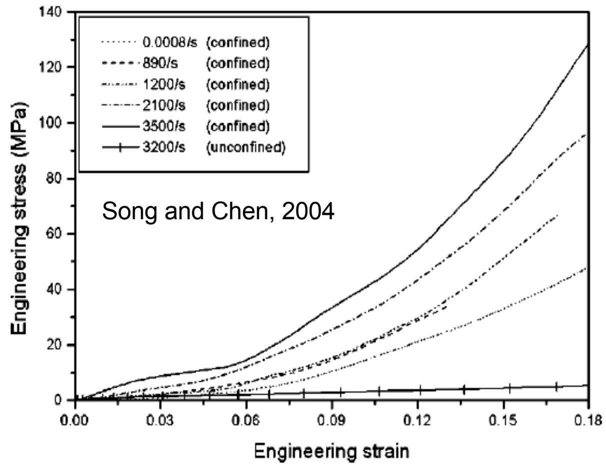
- Typical shock isolation design
  - Spring-dashpot system
  - The object feels
    - Lower amplitude of excitation
      - Lower impact energy
    - Lower frequencies
  - Always good for survivability
  - But NOT always good for functionality

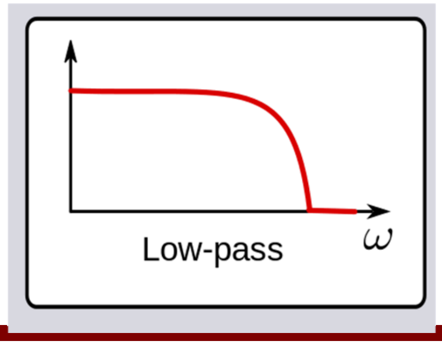


Shock Isolation/Mitigation

- Rubbers have been mostly used as shock isolation/mitigation materials
- Rubbers are typically a spring-dashpot system
  - Mechanical characteristics determine their shock isolation/mitigation performance
    - Non-linear stress-strain response
    - Significant strain-rate effect
    - Significant stress-state effect
  - Phenomenon
    - High frequencies being killed
    - Shock amplitudes being attenuated
  - Good for most but not all of cases
    - Example: upon shock/impact, some internal sensors need to be not only survived but also properly functioned to record actual external shock/impact signals, i.e. accelerations.
    - Low-pass requirement
      - Kill high frequencies but allow all low frequencies pass through without significant attenuation

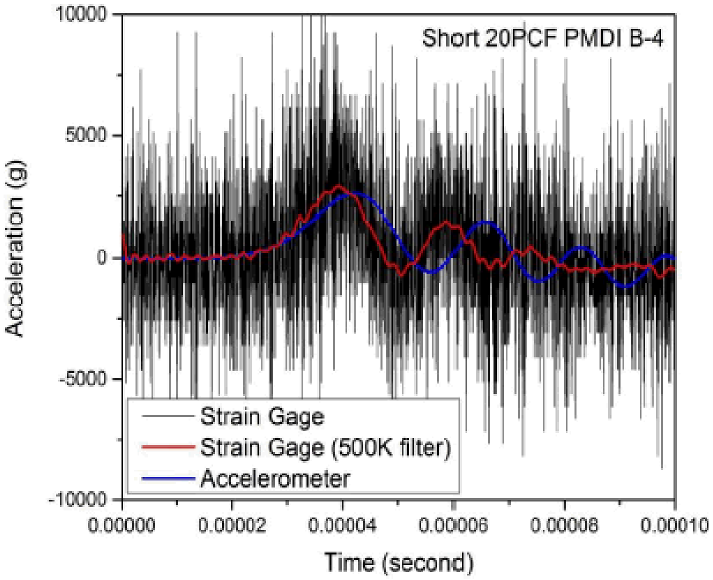


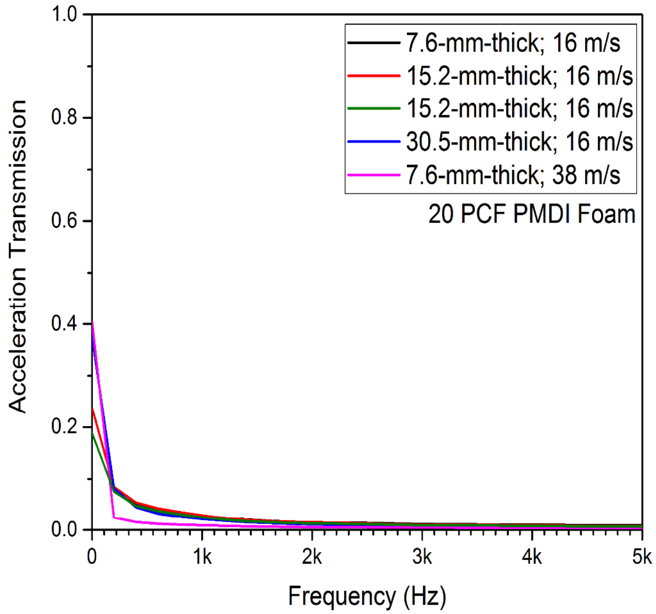




Previous Related Work

- **B. Song, K. Nelson. (2015) Dynamic Characterization of Frequency Response of Shock Mitigation of a Polymethylene Diisocyanate (PMDI) Based Rigid Polyurethane Foam. *Latin American Journal of Solids and Structures* 12(9):1790-1806**
  - Cutoff frequency was **independent** of **specimen thickness**
  - Cutoff frequency was **dependent** on **impact speed**
  - **Cutoff frequency ~1.5 kHz**
    - **Above 1.5 kHz, almost 100% attenuated**
    - **Below 1.5 kHz, attenuation was down to ~80%**
  - **PMDI foam is a good shock mitigation material, but not a low-pass shock mitigation material**





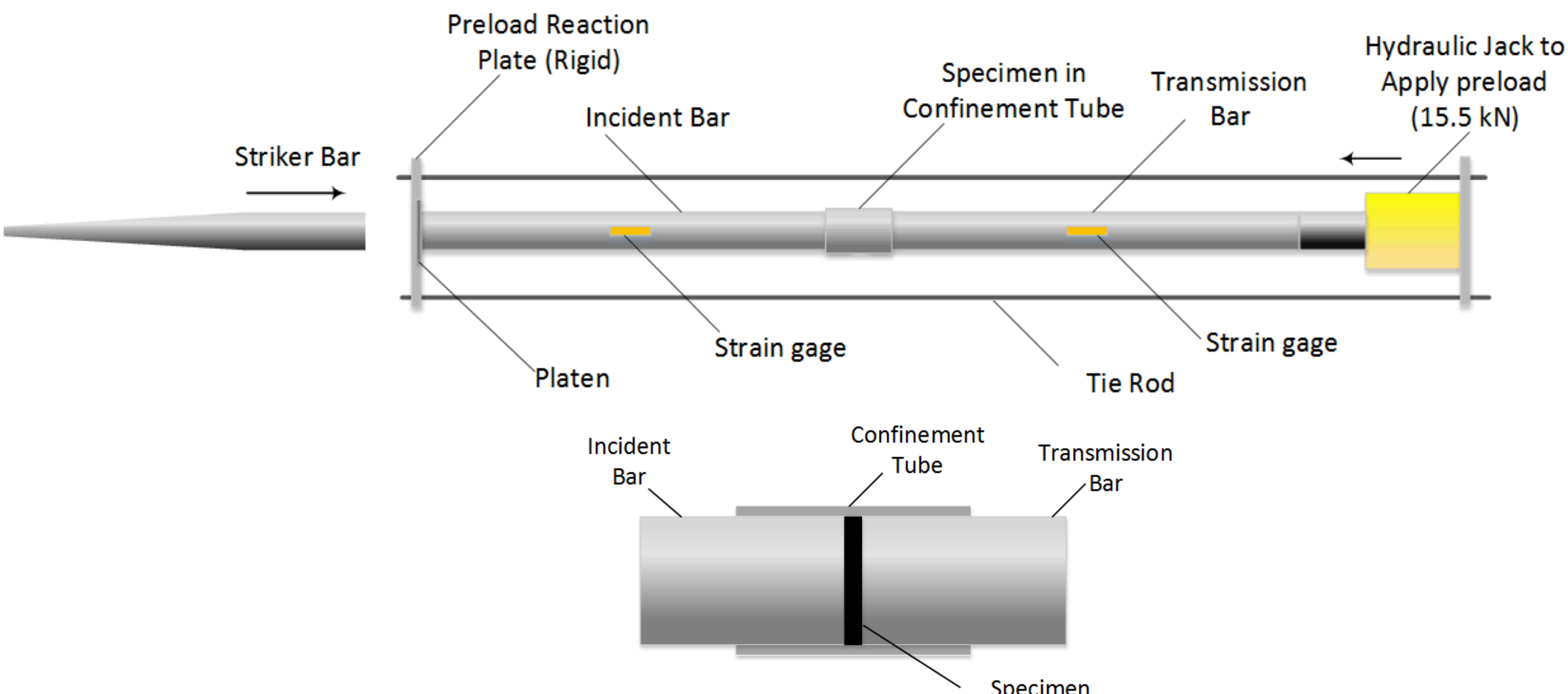
This Study…

- Low-pass mechanical filter characterization/evaluation
- Focus: transmitted acceleration characteristic at different frequencies through shock isolation/mitigation materials
  - Materials
  - Geometries
  - Pre-loads

Material	Density (kg/m^3)	Durometer (Shore A)	Thickness (mm)	Diameter (mm)
Polyurethane	1233 ± 7.4	80	3.08	25.4, 19.05, 15.88, 9.53
Neoprene	1159 ± 22.7	70	2.97	25.4, 19.05, 15.88, 9.53
EPDM	1321.5 ± 3.9	60	3.10	25.4, 19.05, 15.88, 9.53

Kolsky Bar Methodology

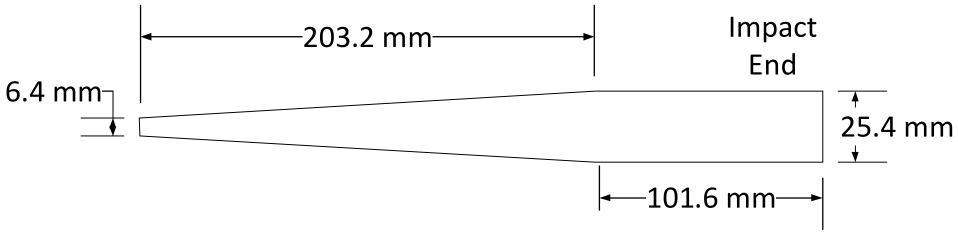
- Hydraulic jack is used to apply axial pre-load
- Pre-loads of up to 15.5 kN (3500 lb-f) can be applied
- Steel tube passively confines specimen
- Tapered tungsten striker

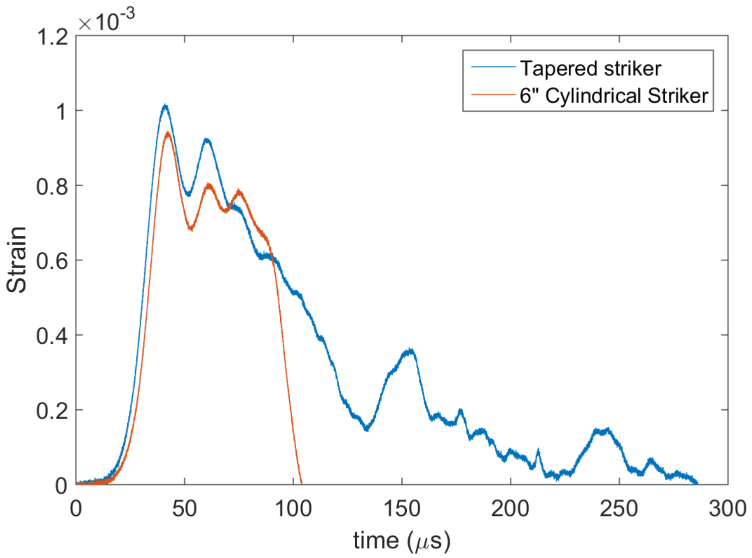


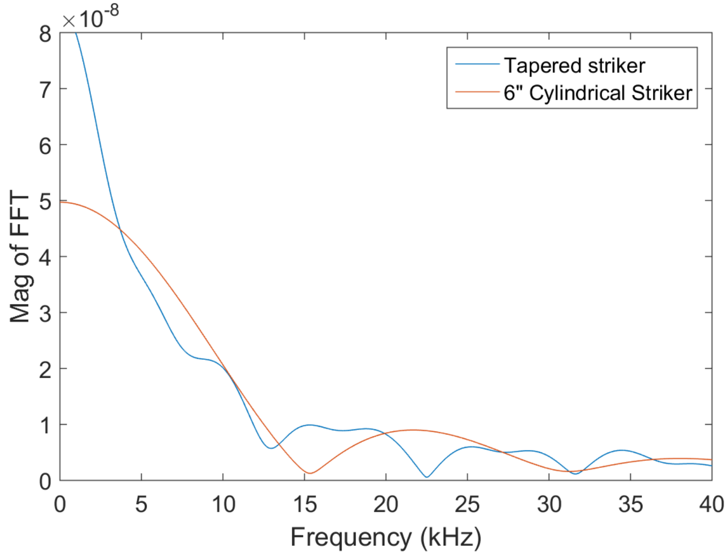
Confinement Tube Cutaway

Tapered Tungsten Striker

- Tapered striker was used to increase the range of frequency content
- Taper + impedance mismatch causes long unloading tail
- Increases the maximum frequency content from 15 to 23 kHz
- No pulse shaper or grease was used







Acceleration Transmission

- Input and output accelerations are calculated using strain signals

$$a_{input}(t) = \frac{dV_{input}(t)}{dt} = C_0 \frac{d(\varepsilon_i(t) - \varepsilon_r(t))}{dt}$$
$$= a_i(t) - a_r(t)$$

$$a_{output}(t) = \frac{dV_t(t)}{dt} = C_0 \frac{d\varepsilon_t(t)}{dt} = a_t(t)$$

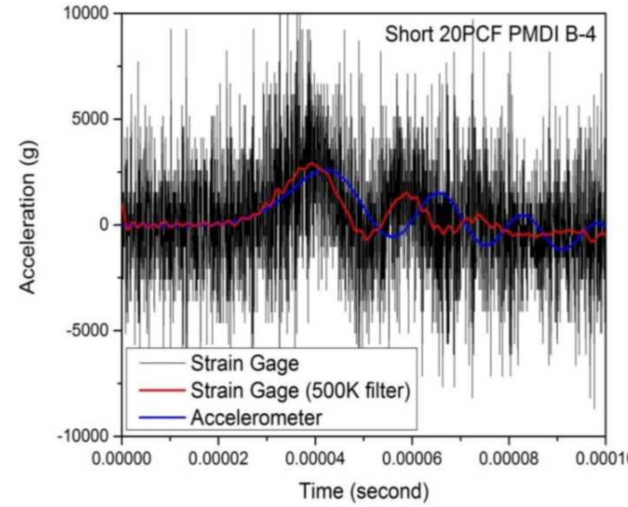
- Accelerations are translated to frequency domain by Fourier transform

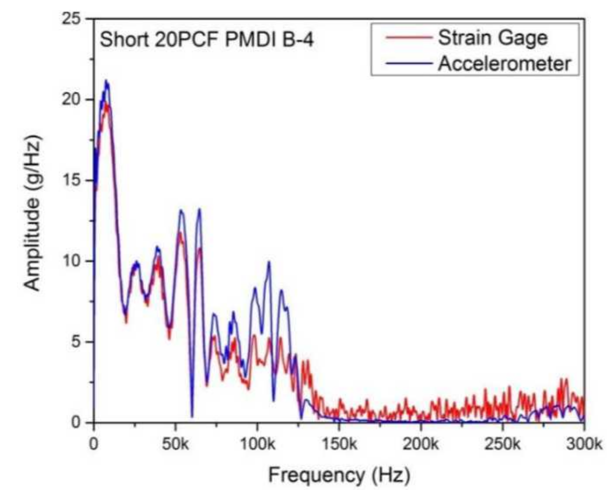
$$a(f) = B(f)e^{-j(2\pi f + \phi)}$$

- Acceleration transmission ratio is calculated

$$\delta_{AT}(f) = \frac{B_t(f)}{B_i(f) - B_r(f)}$$

- Dispersion should not affect the frequency analysis

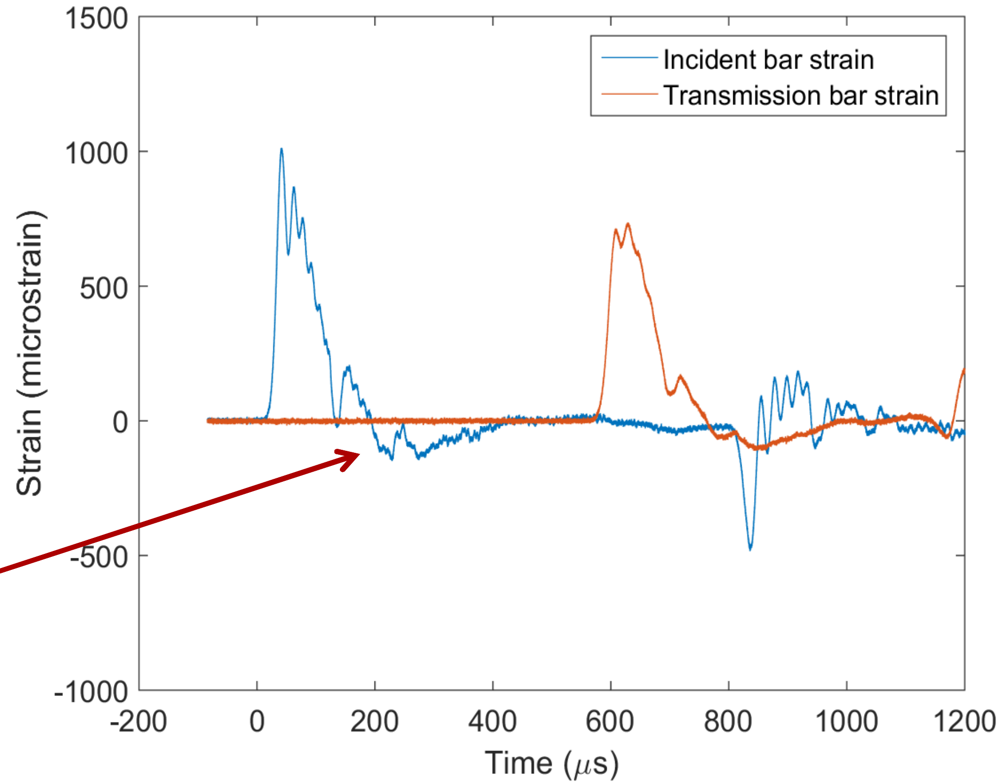




Song and Nelson, 2015

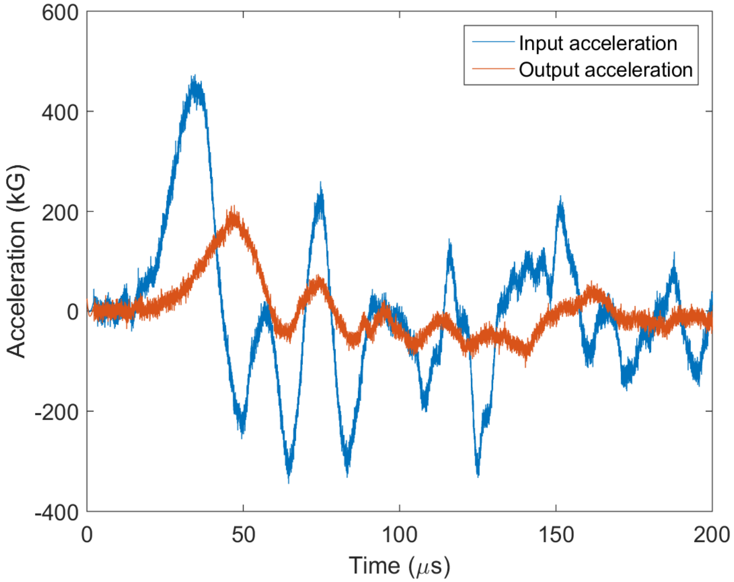
Typical Oscilloscope Record

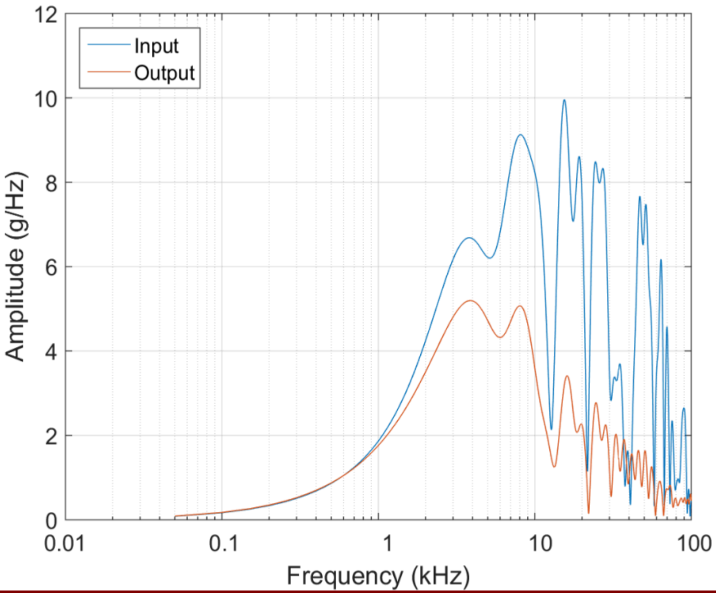
- Original record from an experiment on preloaded (15.5 kN) polyurethane rubber

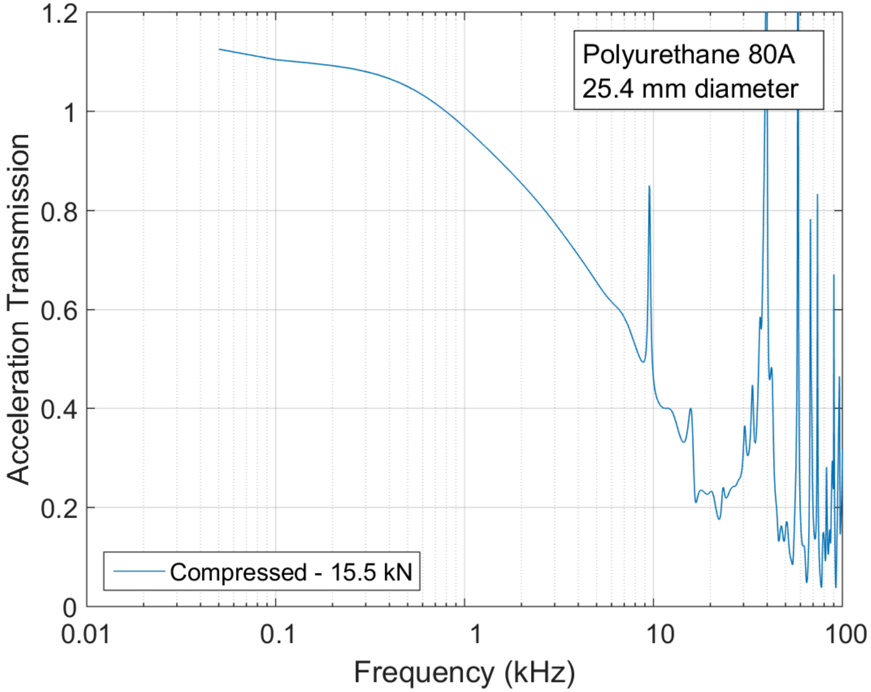


Incident pulse goes negative during unloading

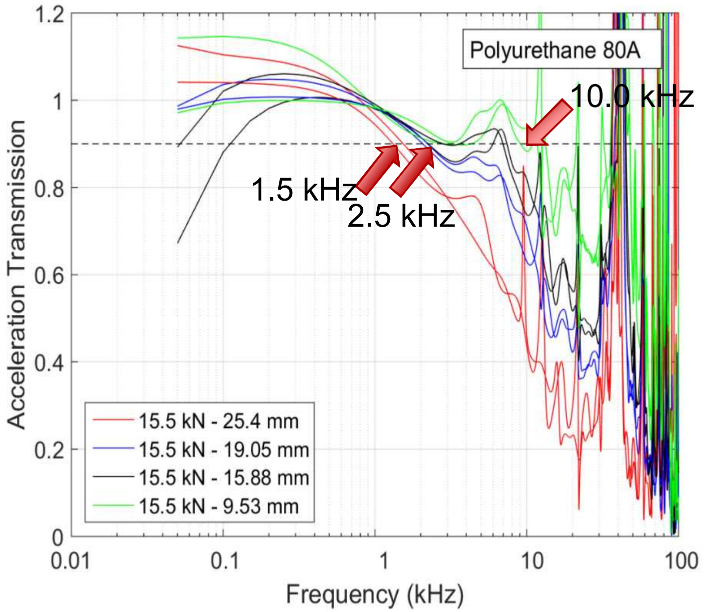
Data Reduction Procedure

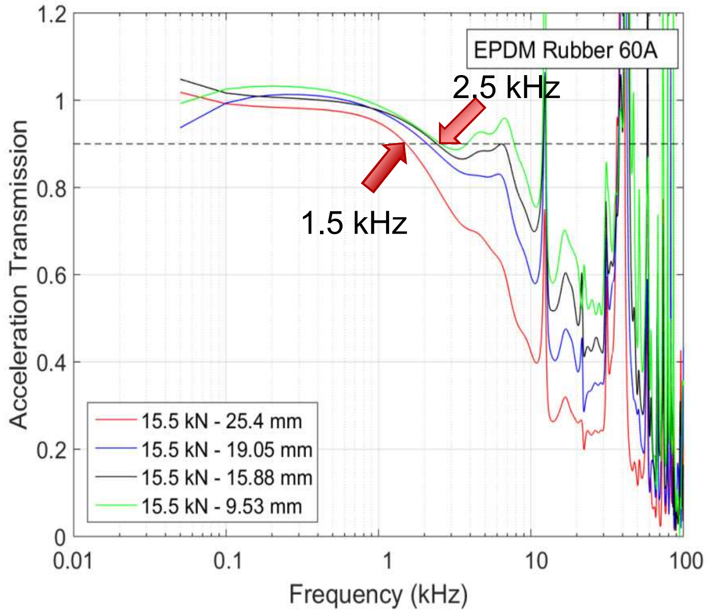


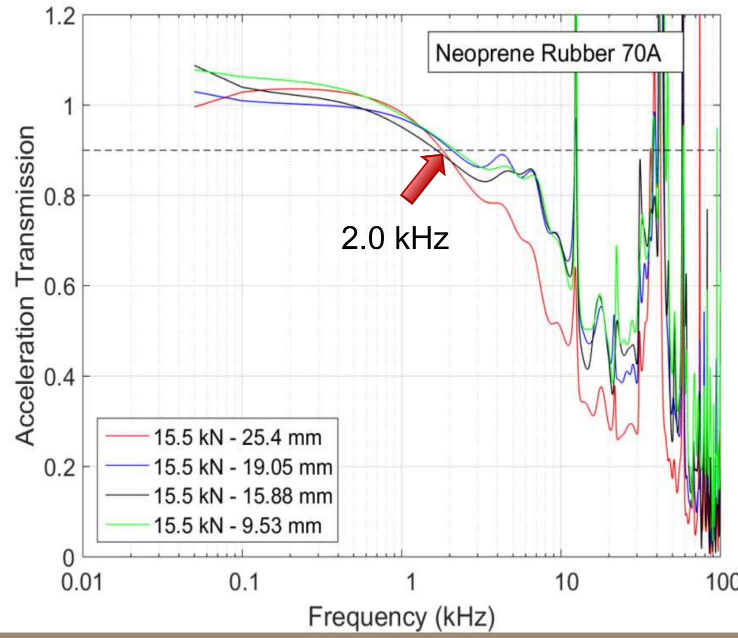




Results

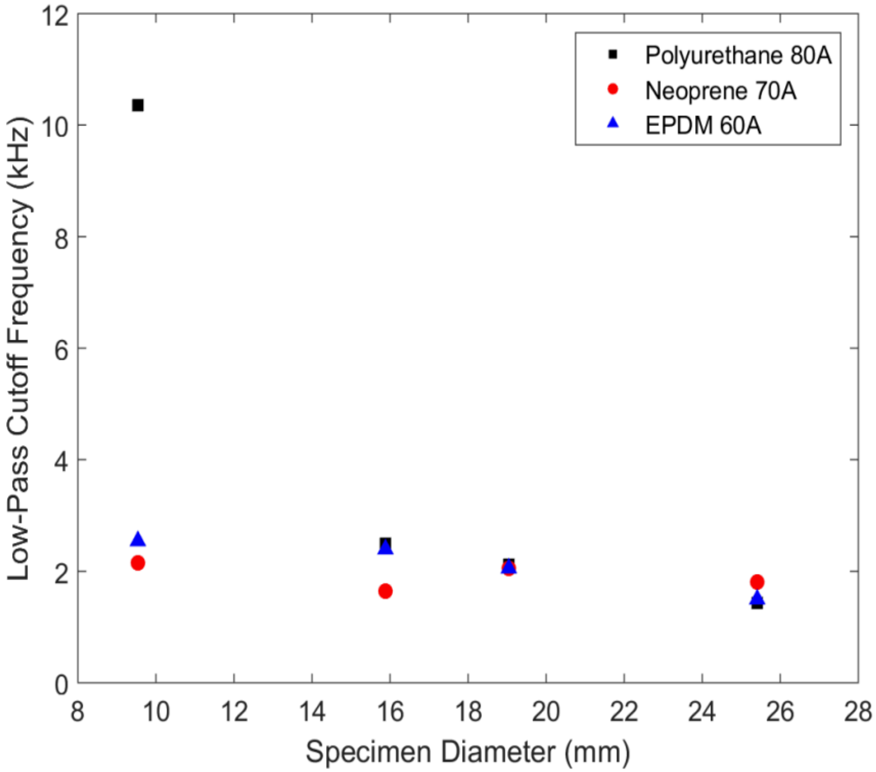

Polyurethane 80A
10.0 kHz
1.5 kHz
2.5 kHz
Acceleration Transmission
Frequency (kHz)
15.5 kN - 25.4 mm
15.5 kN - 19.05 mm
15.5 kN - 15.88 mm
15.5 kN - 9.53 mm

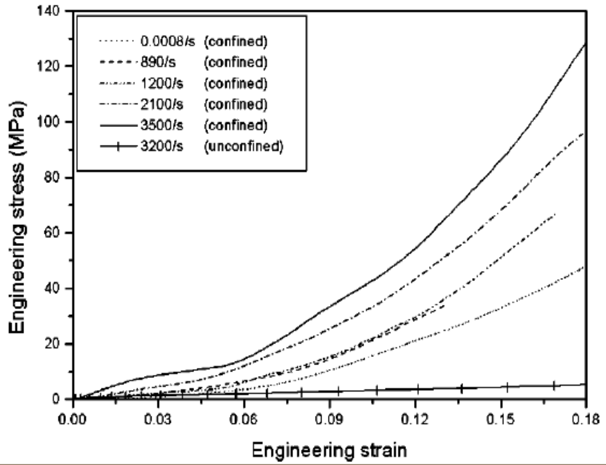

EPDM Rubber 60A
2.5 kHz
1.5 kHz
Acceleration Transmission
Frequency (kHz)
15.5 kN - 25.4 mm
15.5 kN - 19.05 mm
15.5 kN - 15.88 mm
15.5 kN - 9.53 mm


Neoprene Rubber 70A
2.0 kHz
Acceleration Transmission
Frequency (kHz)
15.5 kN - 25.4 mm
15.5 kN - 19.05 mm
15.5 kN - 15.88 mm
15.5 kN - 9.53 mm

Effect of specimen diameter on low-pass cutoff-frequency

- Polyurethane 80A shows the most effect of specimen diameter
- Neoprene 70A shows almost no effect of specimen diameter
- Effect of specimen diameter
  - Preloaded to larger strains at the same pre-load
  - Significant non-linear mechanics response





Conclusions

- A Kolsky compression bar setup was modified with preload capability, passive confinement, and a tapered striker for low-pass mechanical filter characterization of three rubbers - polyurethane, EPDM, and Neoprene

- Each material showed different low-pass cutoff frequency response

- Key parameters to affect the low-pass cutoff frequencies
  - Material's non-linear rate-dependent stress-strain response
  - Initial stress and strain states
    - Specimen geometry
    - Pre-load
  - To fully understand this behavior, confined and unconfined stress-strain behavior must be investigated

- More experiments at different stress-states, preloads, and impact speeds are needed to fully understand low-pass mechanical shock response