

## Benefits of Using Band-Limited Damping in Explicit Dynamics FEA Simulations

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### Overview

- Inspiration for using Explicit Dynamics Models related to PVSS analysis.
- Simplistic demonstration showing how damping in such models distorts PVSS results.
- A bit about damping techniques and BLMD (Band Limited Material Damping).
- Example application – Container Impact.
- A few more thoughts about damping.
- Where does Bodie Tech come in ???



## Inspiration

- You want to shock-test a component or subsystem on a new product.
  - The component / subsystem is denoted as the AUT (Article Under Test).
  - You are needing a Shock Spectrum that characterizes the intended shock environment the AUT will be exposed to. This will guide the testing.
- As this is a new design concept, NO existing Shock Spectra curves are available to guide you.
  - Additionally, the full product does not exist in hardware yet, so physical testing to get the Spectra describing the driving shock at the AUT attachment points is not possible.
- You will rely on **transient Explicit FEA simulations** of the full product to gain the needed data to derive the Shock Spectra at the interface locations for the AUT.
  - Run a variety of FEA simulations with different impact scenarios.
  - Store transient nodal accelerations at interface locations of the AUT to the larger structure.
  - Compute Shock Spectra for various cases (several nodes & 3 directions).
  - Create representative envelopes of Spectra from multiple cases (per direction).
  - You now have Spectra, continue the AUT evaluation as usual.



## Consider an FEA Simulation of a Shock Event

### • Cell Phone Impact

1. The cell phone and cover is represented with a detailed FEA model. A shock is applied to the corner of the phone by impacting it against a rigid surface.
2. From the FEA model, output a transient signal of acceleration vs time at the location of the camera inside the phone (the model does not have detailed representation of camera).
3. Calculate a PVSS on this transient acceleration data to provide this to a vendor that makes the camera. This will be the spec the camera must survive.



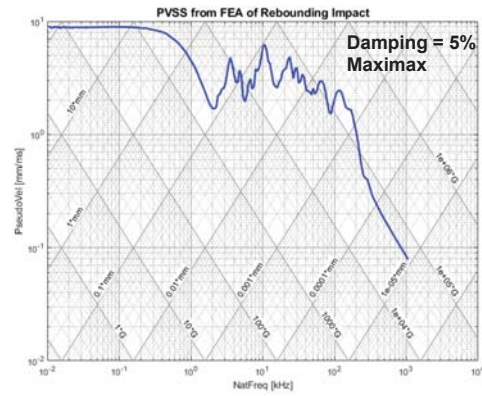
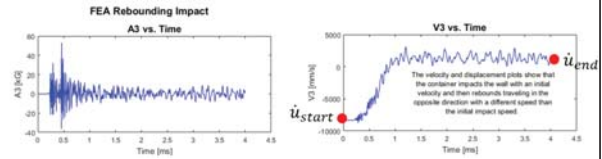
### • Ship Under Attack

- Same 3 steps as above, but with an FEA model of ship in water being exposed to an explosion.
- Step 3 will calculate PVSS from output at a location in the ship where sensitive equipment (not modelled in detail) resides. Provide PVSS to vendors of such equipment for them to test equipment. There would likely be some margin added to the PVSS.



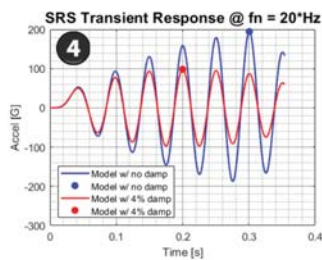
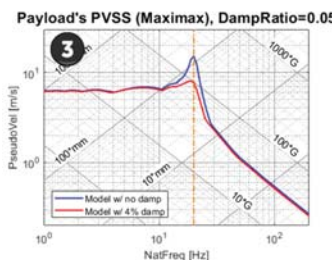
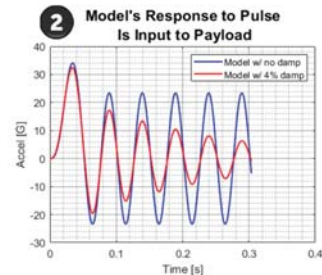
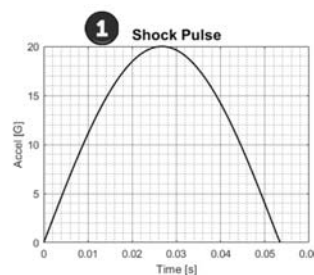
## These Approaches Rely Heavily on Determining A PVSS Curve

- For a given impact/shock direction, the PVSS characterizes the driving shock environment going into the AUT.
  - Thus component / subsystem testing will be based on these PVSS curves.
    - If they somehow are over-estimating the environment, we will over-test the AUT.
    - If they somehow are under-estimating the environment, we will under-test the AUT.
- The PVSS curves here are derived from time-transient FEA models.
  - Remember, full hardware is not in existence yet!
- The accuracy of our PVSS curves are dependent on the accuracy of our full product-level transient FEA models.
  - What could go wrong here ???



## Simplistic Representation of the Modeling Scenario

- Shock pulse is transient input to the FEA model.
- Two FEA models are created, one with no damping (typical explicit FEA approach) and one with 4% critical damping everywhere. The plots are transient accel output from models.
- Compute PVSS from step 2. Notice that the model with no damping has much larger PVSS response.
- Time-domain SRS responses shows how ringing in step 2 causes excessive PVSS result.



**Damping in FEA model has big influence on PVSS**



## Damping Approaches in Transient Explicit Dynamics Simulations

- Damping in transient simulations typically comes in multiple ways:

### 1. Algorithmic damping

- A small amount of apparent damping occurs from the numerical method used to integrate the equations, or it is part of the numerical approach to stop excessive high-frequency ringing.

### 2. Material damping

- Rayleigh Damping - Intended to represent physical damping of materials (has very limited abilities to achieve this).
- Band-Limited Material Damping - Define constant damping ratio over a finite range of frequencies for transient models.

#### Very useful!

- Guidance for defining frequency range:  
Set  $f_{Low} = 0.6 \cdot f_{n1}$  and  $f_{High}/f_{Low} \leq 100$ .

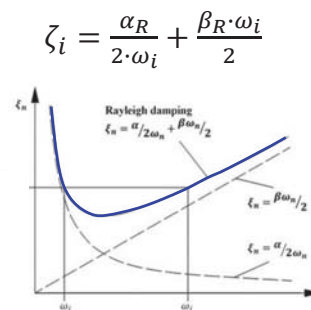
### 3. Other inelastic material behaviors

- Viscoelasticity and plasticity will have the effect of removing energy and appear as a kind of damping in simulations.



## Practical Difficulties Using Rayleigh Damping

- This equation implies mass proportional damping ( $\alpha_R$ ) dampens lower frequencies, and stiffness proportional damping ( $\beta_R$ ) dampens higher frequencies.
  - Rigid body motion has frequency  $\rightarrow 0 \cdot rad/sec$   
 $\Rightarrow$  huge  $\zeta$  damping ratio!
    - Bad for drop simulations or similar (model is in molasse).
  - For very high modes, the damping ratio grows linearly with frequency.
    - This kills the time increment size in Explicit Transient solutions.



$$\Delta t \leq \frac{2}{\omega_{max}} \cdot \left( \sqrt{1 + \zeta_{max}^2} - \zeta_{max} \right)$$

- Additionally, in cases where you want to put a constant damping over a range of modes, it is not possible to define  $\alpha_R$  and  $\beta_R$  and achieve that. There is always a dip in the range desired.



## Band-Limited Material Damping (BLMD) via the HSW Method Also Referred to as Frequency-Range Material Damping

- The technique is based on the following paper (HSW are 3 author's last name initials):
  - Y. Huang, R. Sturt, M Willford, "A Damping Model for Nonlinear Dynamic Analysis Providing Uniform Damping Over a Frequency Range", *Computers and Structures*, July 16, 2018.
  - Key concepts from paper:

The goal of the proposed model is to numerically impose energy dissipation on any material such that it

- approximates uniform damping over a frequency range
- requires no a priori knowledge of the constitutive models
- produces zero damping force for rigid-body motion

Damping ratio,  $\zeta$ , relative to damping factor,  $\xi'$   $\zeta = \xi' / 2$

[https://www.researchgate.net/publication/328827267\\_A\\_damping\\_model\\_for\\_non\\_linear\\_dynamic\\_analysis\\_providing\\_uniform\\_damping\\_over\\_a\\_frequency\\_range](https://www.researchgate.net/publication/328827267_A_damping_model_for_non_linear_dynamic_analysis_providing_uniform_damping_over_a_frequency_range)

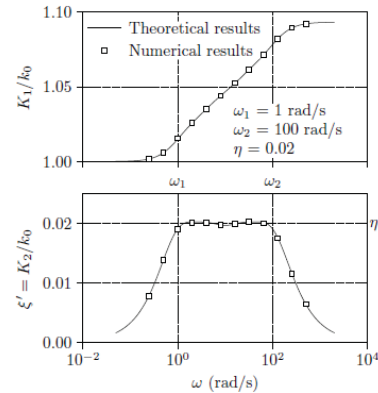


Figure 1: Dynamic stiffness of the proposed damping model



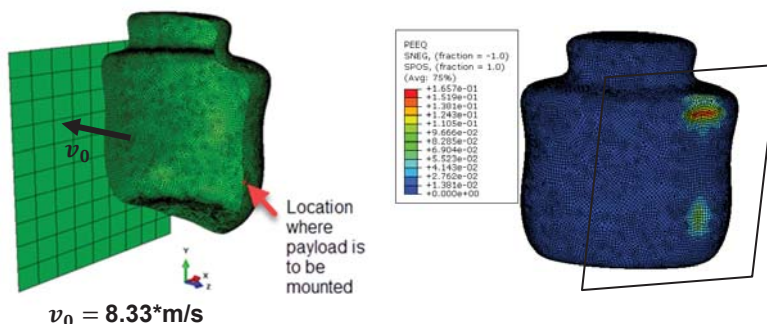
## Implementing BLMD Robustly in an Explicit FEA Code is Non-Trivial

- Both LS-Dyna and Abaqus/Explicit have implemented BLMD options in their FEA codes for applying material damping.
- LS-Dyna**
  - They implemented it first, on or around the year 2018 (I am not sure of the exact year nor the initial LS-Dyna release version). It is called *Frequency-Range* damping.
  - The first couple of code releases with this feature had some issues.
  - By around the year 2020 to no later than 2021, the LS-Dyna implementation appeared to be robustly working on a variety of problems based on experiences of this instructor's colleagues at Magic Leap.
- Abaqus/Explicit**
  - BLMD became available in Abaqus 2021, FP.CFA.2050.
  - The initial implementation had a few issues related to energy balance tracking and solution instability.
  - By the release of **Abaqus 2022-HF4** (Hot fix 4) the implementation appears to be stable and working well based on this instructor's personal test cases that have been explored.



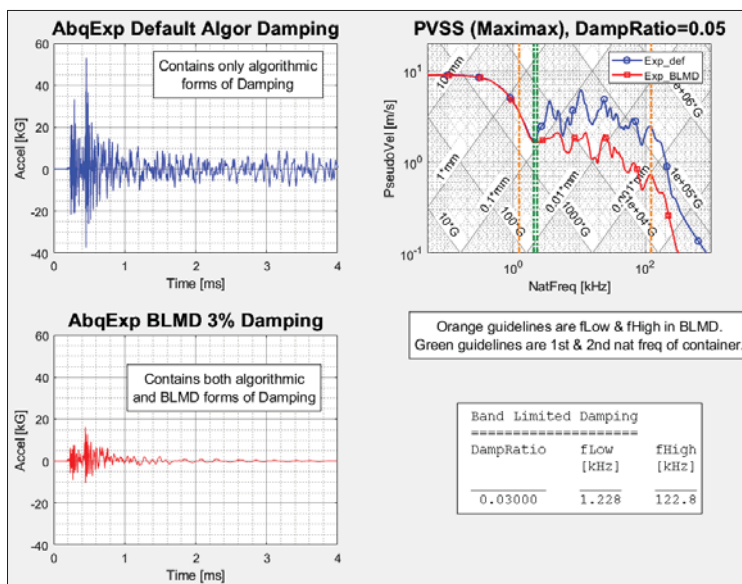
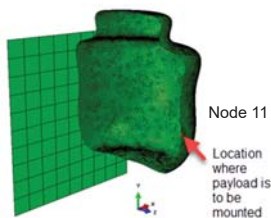
### Example Application - Container Impact

- We need to estimate the shock input environment inside this container at the Payload location noted.
  - The explicit dynamics FEA model includes elastic/plastic behavior in the container material law.
  - Let's compare two versions of the model:
    1. Default algorithmic damping only.
    2. Default algorithmic damping + BLMD (3%)



### Demonstrating How Ringing Influences PVSS

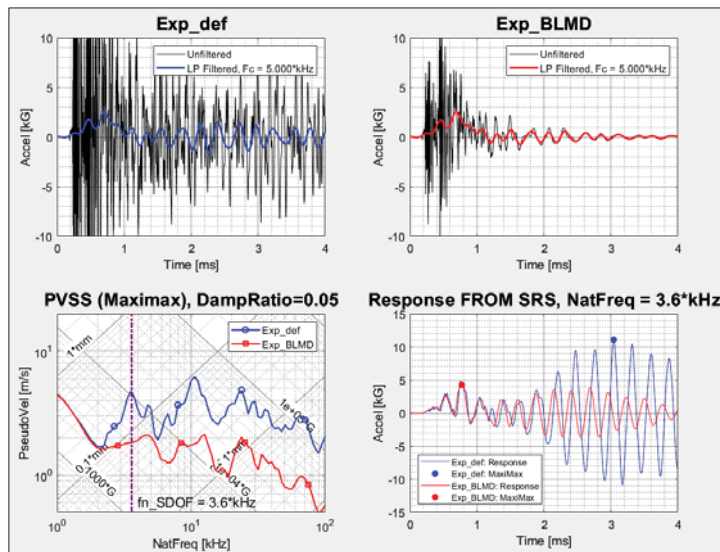
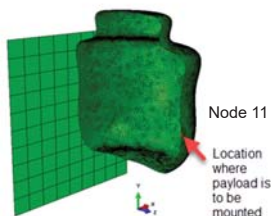
By adding Band- Limited Material Damping (BLMD), we reduce higher frequency content in the solution, but more importantly we lessen the frequency content from excessive ringing.



## Comparing Various Solutions - Explaining How Ringing Influences PVSS

Note: the individual SDOF responses used to compute a PVSS are most sensitive to frequency content near the SDOF natural frequency.

Here we evaluate the PVSS at  $\text{NatFreq} = 3.6 \text{ kHz}$  using data LP filtered at  $5 \text{ kHz}$  so you can see the essence of what is driving the PVSS response.



**Damping in FEA model has big influence on PVSS**

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## Determining Damping Ratio

- Unfortunately, the analyst rarely has accurate knowledge of damping to guide the specification of damping ratio precisely. Instead, you will have to rely on approximations, "guesstimates", and sensitivity studies to determine what approach and value, if any, to utilize.
- Damping data from physical modal testing, if available, might be one source to consider.
  - This data will typically be a table of damping ratio values for various modes.
    - You will need to determine a single representative value because BLMD cannot represent a table of values that are frequency dependent.
  - Physical modal testing usually relies on linear structural response.
    - There is a good chance that your model in Explicit Dynamics will be pushed into the nonlinear regime and other influences will add to the apparent damping that would occur in your physical structure.
- In many cases, the use of damping in the model does not need to be precise, but instead it needs to just be reasonable.
  - Tuning damping values using surrogate physical test set-ups can be very helpful.



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# I Thought This Was a Vendor Session ... So Where Does Bodie Tech Come In ???

- To successfully apply this type of approach, you need knowledge of important subtleties and additional concepts (avoiding aliasing and much more), plus software that makes the needed data processing calculations easy, and that can manage a ton of such calculations in many scenarios.
  - **That is where Bodie Tech Comes In!**
- Bodie Tech offers:
  - **Noisy Data Training**
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  - **Expert Consulting**
    - Over 30+ years of experience tackling difficult transient nonlinear mechanics problems.
- Bodie Tech's offerings will help you successfully apply this type of complicated, DSP-intensive, work-flow, and many others too!

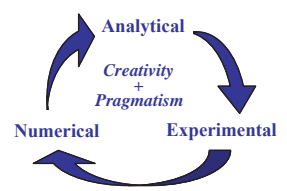
**This DSP seminar should be mandatory for every explicit dynamics user. Ted is a great lecturer.**  
– Pedro Bastias, NACCO

**Your course is the best I have taken in a long time.**  
– Michael J. Iacchei, U.S. Army



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