Damping in explicit LS-DYNA

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What is damping?

- Damping is an effect when the amplitude of oscillations decrease over time.
- For a vibrating body the kinetic and elastic energy in the system is decreased due to, for example, viscous drag or internal friction. The energy is then converted to sound or heat.

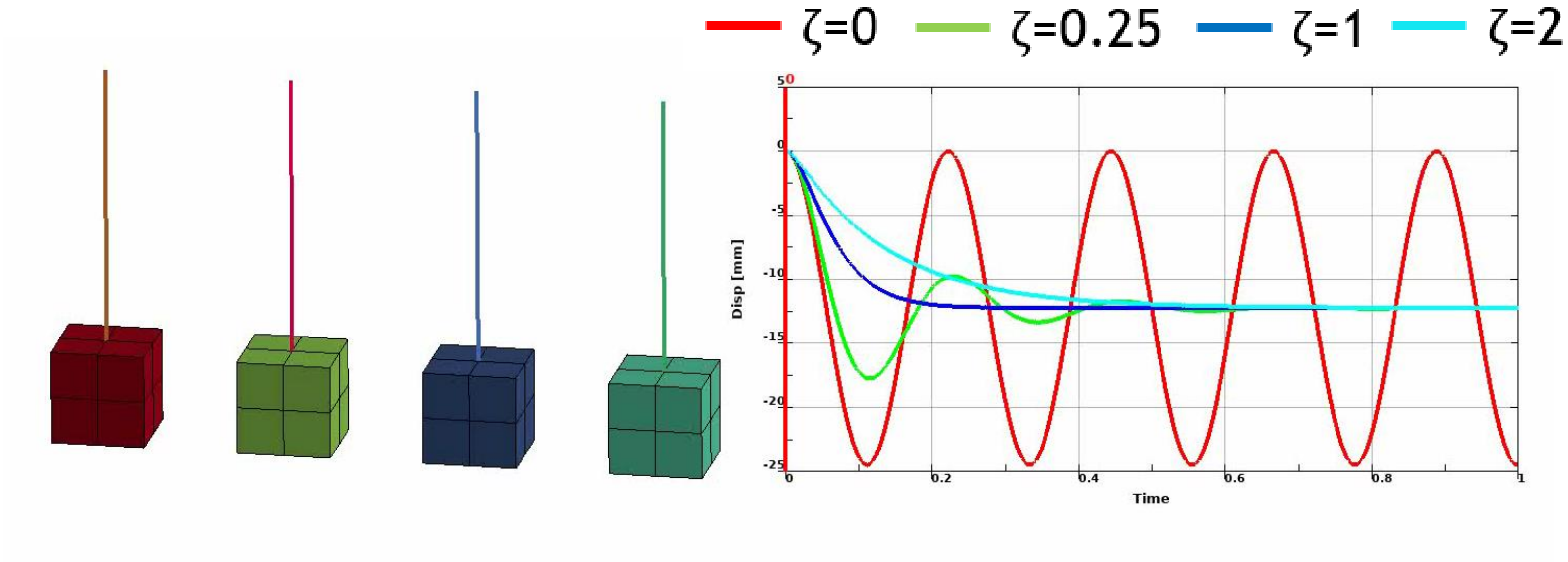
Why use damping in simulations?

- In a typical finite element simulation there is no natural damping effect included. The air surrounding the model is not present, and usually there is no internal losses in the material either.
- Numerial damping must be added in the model to include these effects.

- In quasi-static simulations the loading rate is often faster than in the physical test. This will increase the dynamic effects in the model and may induce unwanted oscillations that are not present in the physical test.
- Damping can be added in the model to reduce the oscillations.

Damping ratio

- The damping ratio (ζ) is the damping in a system relative to the critical damping
- $\zeta = \frac{Actual\ damping}{Critical\ damping}$
  - ζ < 1 : Underdamped. Overshoots the steady state position
  - ζ > 1 : Overdamped damping. No overshoot.
  - ζ = 1 : Critical damping. No overshoot and reaches steady state in minimum amount of time



Rayleigh damping

- Equations of motion:

$$\boldsymbol{M}\ddot{x} + \boldsymbol{C}\dot{x} + \boldsymbol{K}x = \boldsymbol{F}$$

  - $\boldsymbol{M}$: Mass matrix
  - $\boldsymbol{C}$: Damping matrix
  - $\boldsymbol{K}$: Stiffness matrix
  - $\boldsymbol{F}$: External forces

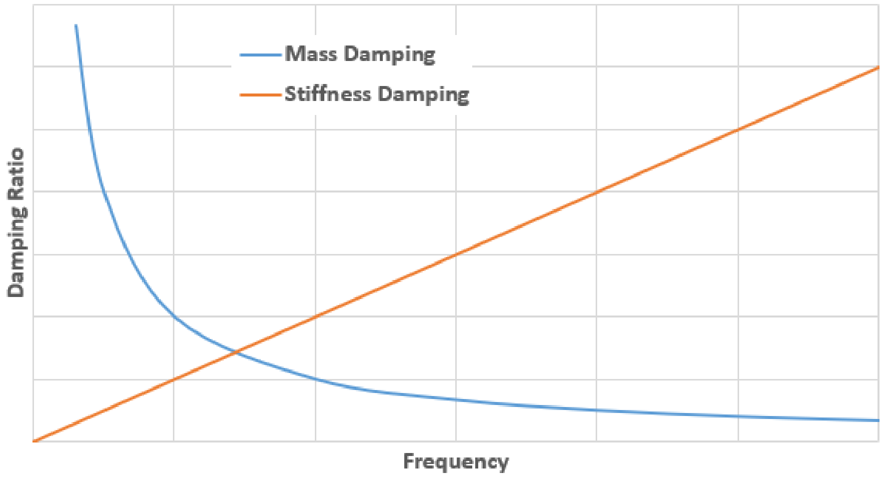
- Rayleigh damping matrix $\boldsymbol{C}$:

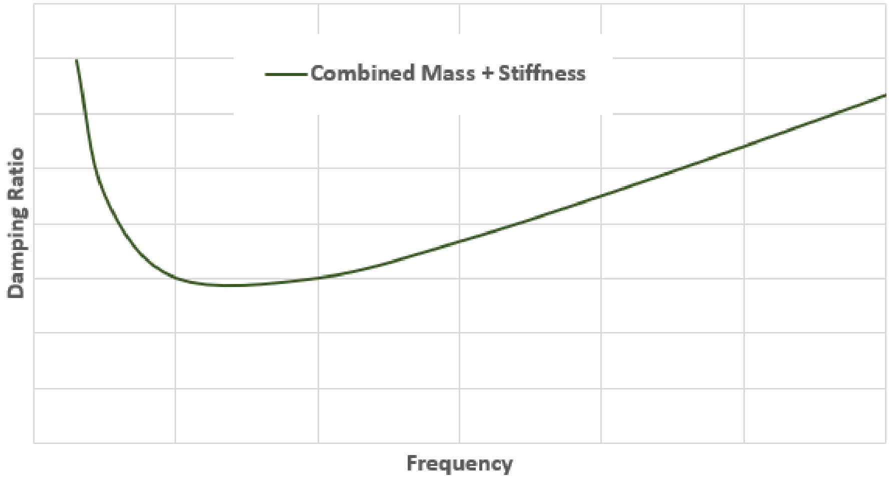
$$\boldsymbol{C} = \alpha\boldsymbol{M} + \beta\boldsymbol{K}$$

  - α: Mass proportional constant
  - β: Stiffness proportional constant

Mass and Stiffness damping

- Mass Weighted Damping
  - Damps the node velocities
  - Proportional to 1/f
  - Effective on low frequencies
  - Rigid body modes will be damped
- Stiffness Proportional Damping
  - Damps the element response
  - Proportional to f
  - Effective on high frequencies
  - Will affect the critical timestep





Damping keywords in LS-DYNA

- *DAMPING_GLOBAL

*DAMPING_GLOBAL							
LCID	VALDMP						

  - LCID: Optional load curve to control the damping
  - VALDMP: Damping Constant

- Mass weighted damping
- Applies to all nodes in the model
- Will damp rigid body motions
- For critical damping, set the constant to $2 * \omega_{min}$
  - ω_{min} = lowest angular frequency mode of interest

Damping keywords in LS-DYNA

- *DAMPING_PART_MASS_[SET]

*DAMPING_PART_MASS_[SET]							
PID/PSID	LCID	SF					

  - PID/PSID: Part ID or Part_Set ID to which the damping is applied
  - LCID: Load curve
  - SF: Scale factor

- Mass weighted damping
- Do not combine with *DAMPING_GLOBAL
- Will damp rigid body motions
- For critical damping, set the constant to $2 * \omega_{min}$
  - ω_{min} = lowest angular frequency mode of interest

Damping keywords in LS-DYNA

- *DAMPING_PART_STIFFNESS_[SET]

*DAMPING_PART_STIFFNESS_[SET]							
PID/PSID	COEF						

  - PID/PSID: Part ID or Part_Set ID to which the damping is applied
  - COEF: Damping coefficient

- Stiffness proportional damping
- Recommended values for COEF: 0.01 – 0.25
- The coefficient is defined such that a value of 0.10 roughly corresponds to 10 % damping in the high frequency domain.
- This damping will affect the critical timestep. It could be necessary to decrease the time step scale factor in *CONTROL_TIMESTEP.

Damping keywords in LS-DYNA

- *DAMPING_FREQUENCY_RANGE_[DEFORM]

*DAMPING_FREQUENCY_RANGE_[DEFORM]							
CDAMP	FLOW	FHIGH	PSID				

  - CDAMP: Damping in fraction of critical
  - FLOW: Lowest frequency of interest
  - FHIGH: Highest frequency of interest
  - PSID: Part Set ID where the damping is applied

- Applies the same damping ratio over a range of frequencies
- Small damping ratios is recommended: < 0.05
- Recommended ratios of F_{High}/F_{Low} : 10 to 300

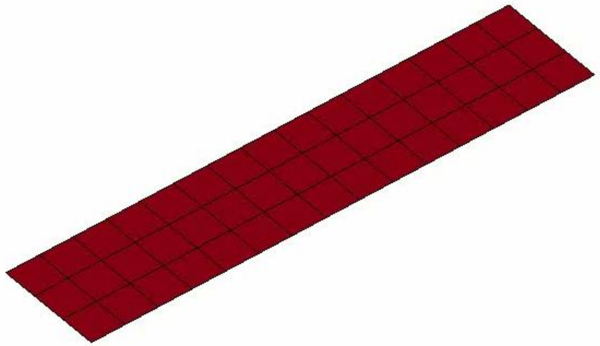
Damping keywords in LS-DYNA

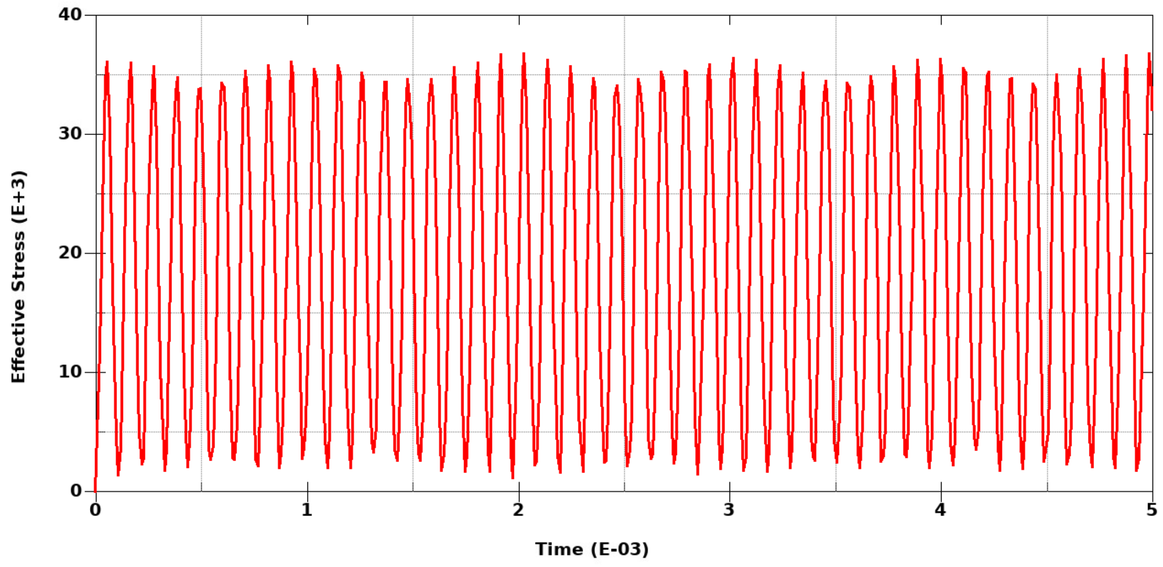
- *DAMPING_FREQUENCY_RANGE
  - A form of mass damping
  - Rigid body motions will be damped
  - Reduces the dynamic stiffness of the model, see the keyword manual

- *DAMPING_FREQUENCY_RANGE_DEFORM
  - A form of stiffness damping
  - Increases the dynamic stiffness of the model, see the keyword manual

Example – Spinning plate

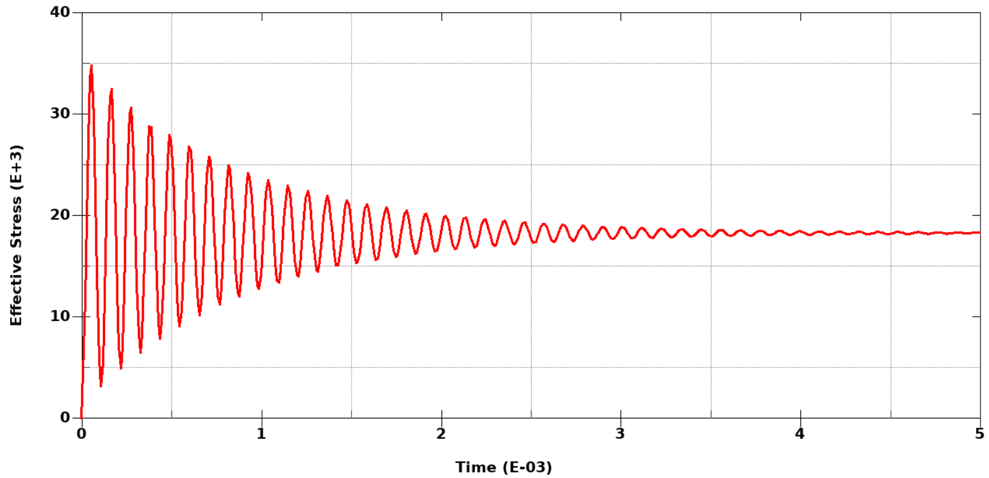
- Plate with initial rotational velocity
- The motion induces high frequency oscillations in the plate (~9000 Hz)



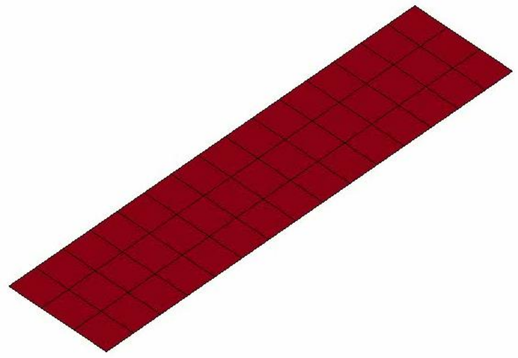


Example – Spinning plate

- *DAMPING_PART_STIFFNESS
  - COEF: 0.10
- The oscillations are being damped out

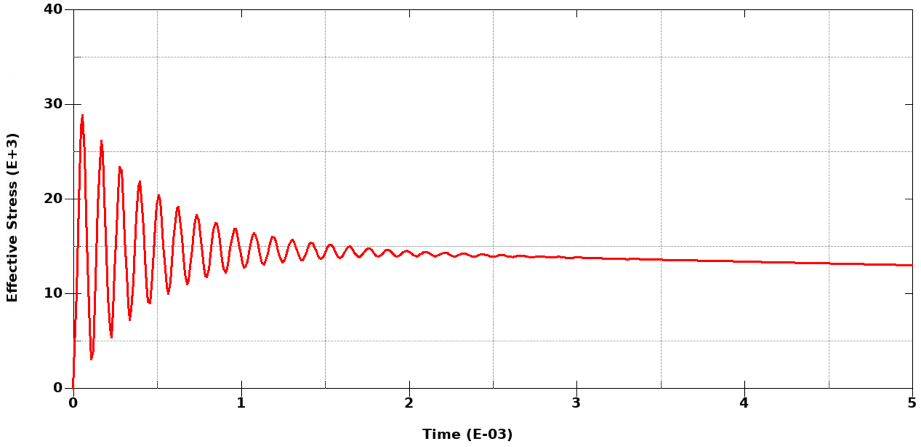


- *DAMPING_GLOBAL
  - VALDMP: 2800 (~0.025 damping ratio)
- The plate stops spinning

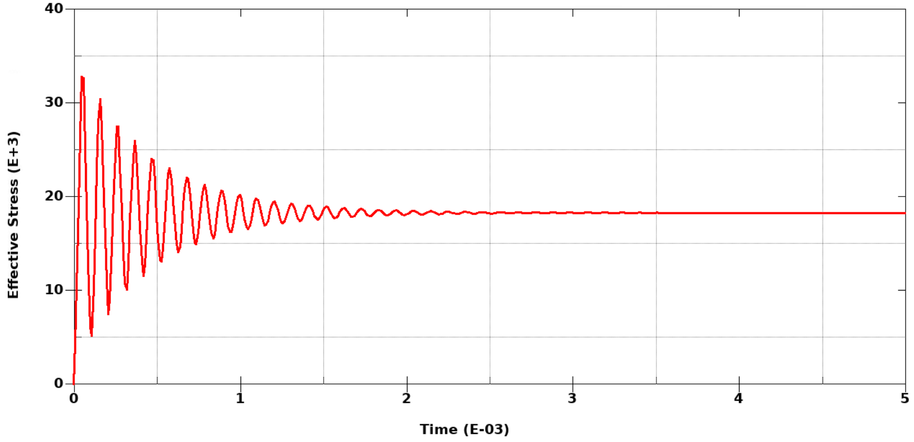


Example – Spinning plate

- *DAMPING_FREQUENCY_RANGE
  - CDAMP: 0.04
  - FLOW: 6000
  - FHIGH: 12000
- The oscillations are being damped out but the rotational velocity decreases slightly

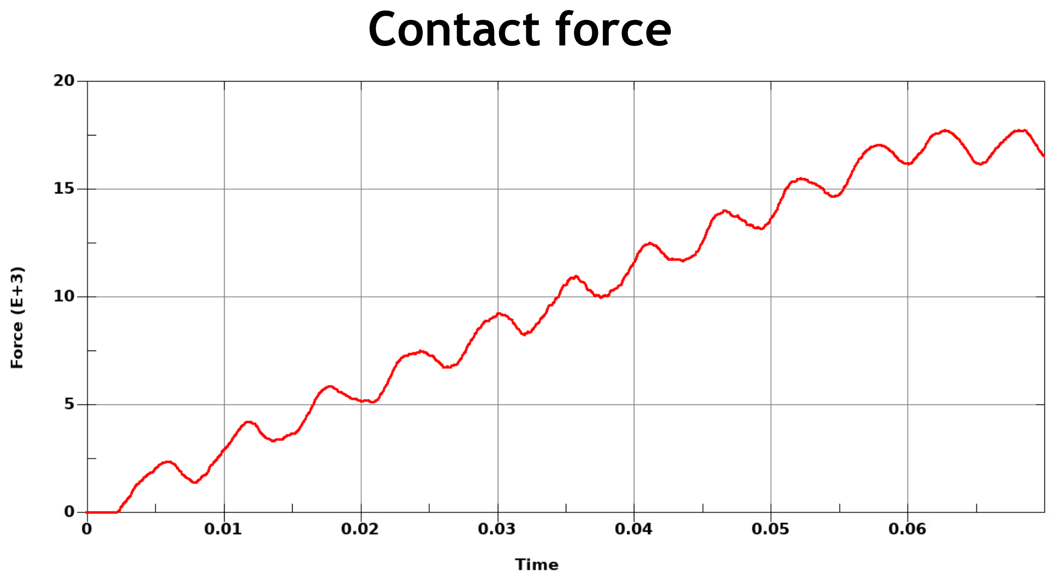


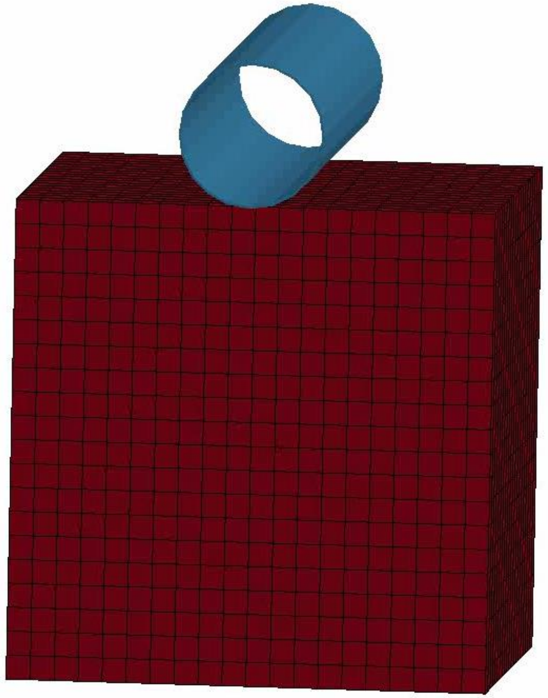
- *DAMPING_FREQUENCY_RANGE_DEFORM
  - CDAMP: 0.04
  - FLOW: 6000
  - FHIGH: 12000
- The oscillations are being damped out without any effect on the rotational velocity



Example – Rubber Block

- A rigid cylinder is pressed against a rubber block with a prescribed force.
- Low frequency oscillations (170 Hz) are visible both in animation and in the contact force.

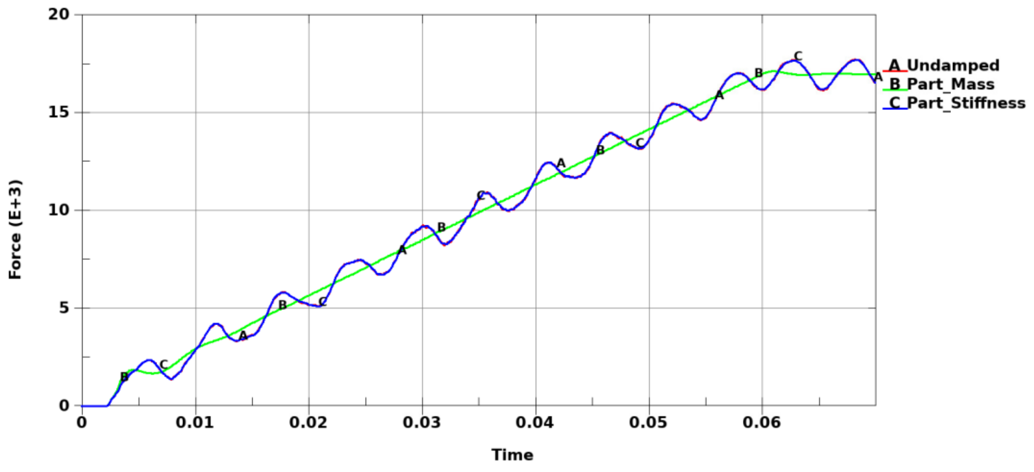


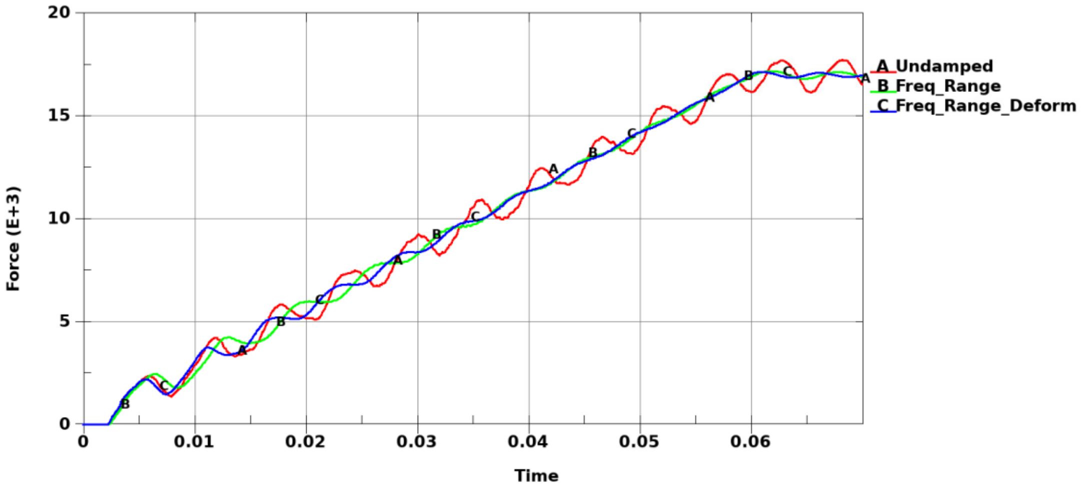


Example – Rubber Block

- *DAMPING_PART_MASS
  - Damping constant: 2100
    (aim for critical damping: $4 * \pi * f$)
- *DAMPING_PART_STIFFNESS
  - COEF: 0.10
- *DAMPING_FREQUENCY_RANGE and _DEFORM
  - CDAMP: 0.05
  - FLOW: 100
  - FHIGH: 1000
- PART_STIFFNESS damping has no effect on the oscillations.
- The other damping options can damp out the oscillations.

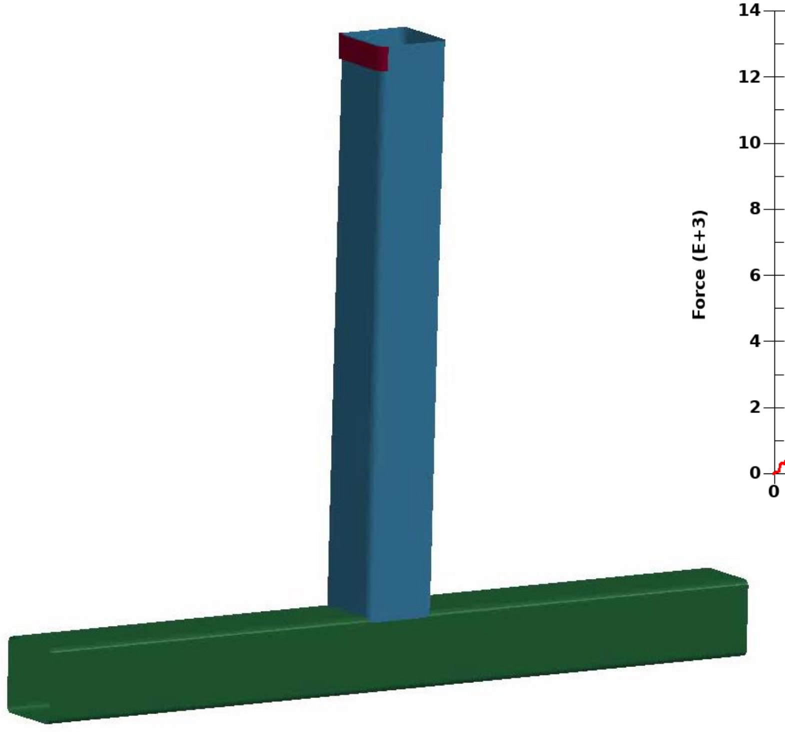
Contact force

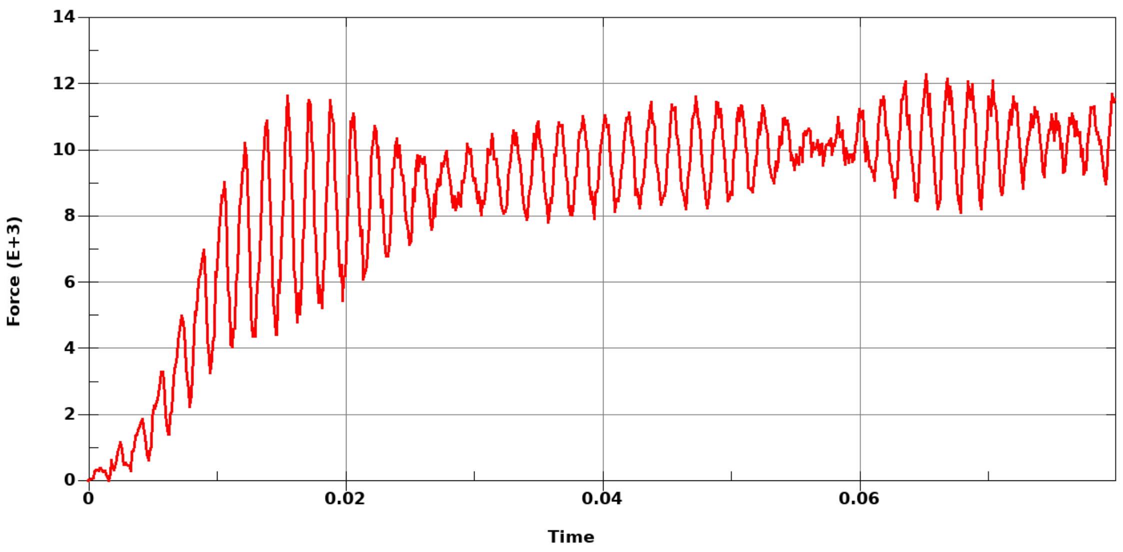




Example – Beam

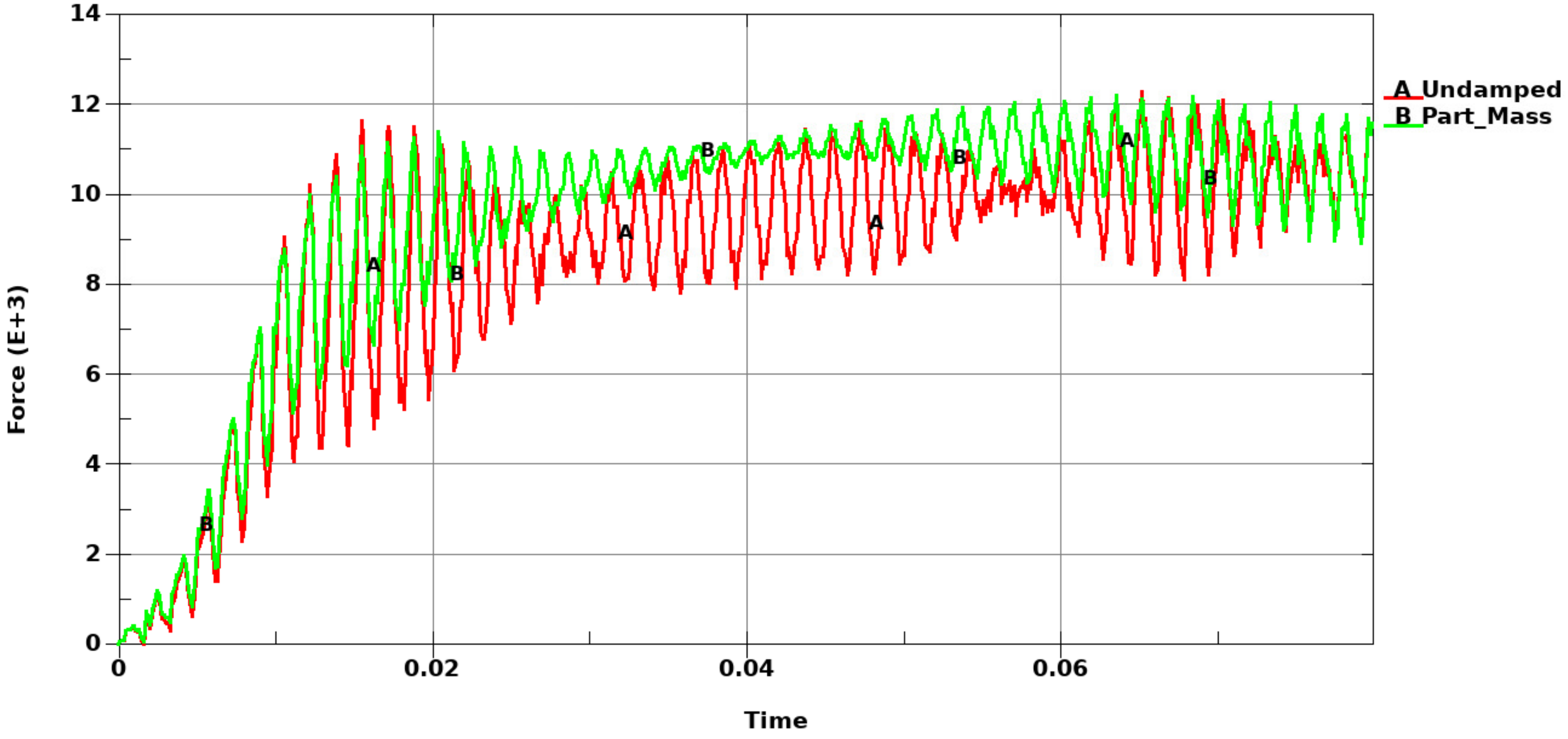
- The top of a vertical beam is pushed by a plate with prescribed motion.
- The lower beam is fixed in both ends.
- The contact force between the plate and beam shows oscillations (~600 Hz)





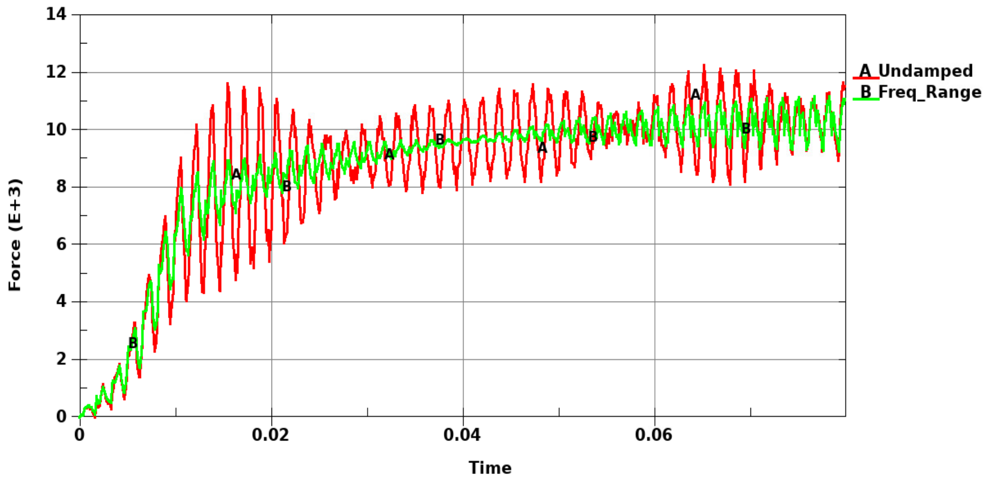
Example – Beam

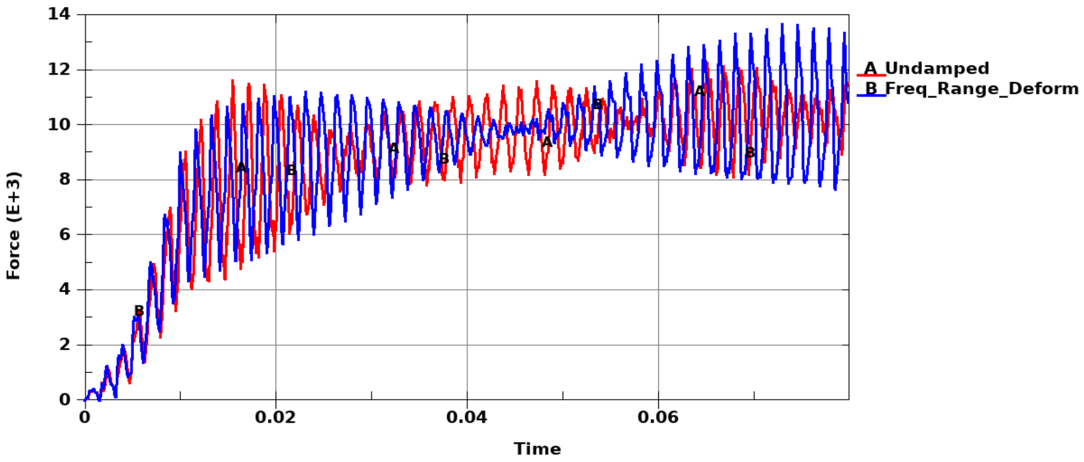
- *DAMPING_PART_MASS
  - Only damping on vertical beam
  - Damping constant: 200 (damping ratio ~ 0.027)
- Some effect on the oscillations but the contact force increases.



Example – Beam

- *DAMPING_FREQUENCY_RANGE and _DEFORM
  - Only damping on vertical beam
  - CDAMP: 0.05
  - FLOW: 100
  - FHIGH: 1000





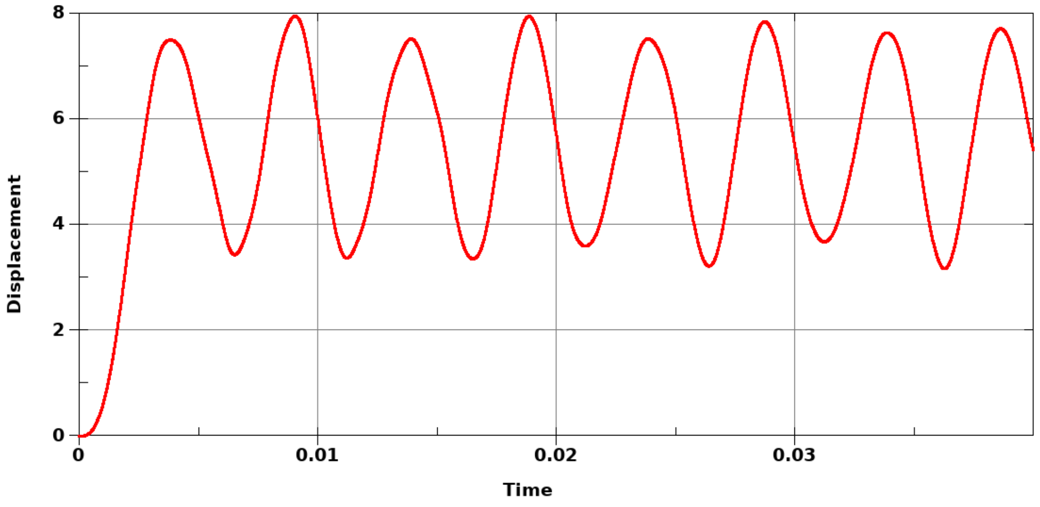
- With _FREQUENCY_RANGE the oscillations decrease but are not fully damped out

- With the _DEFORM option the oscillations even increases

Example – Car tire

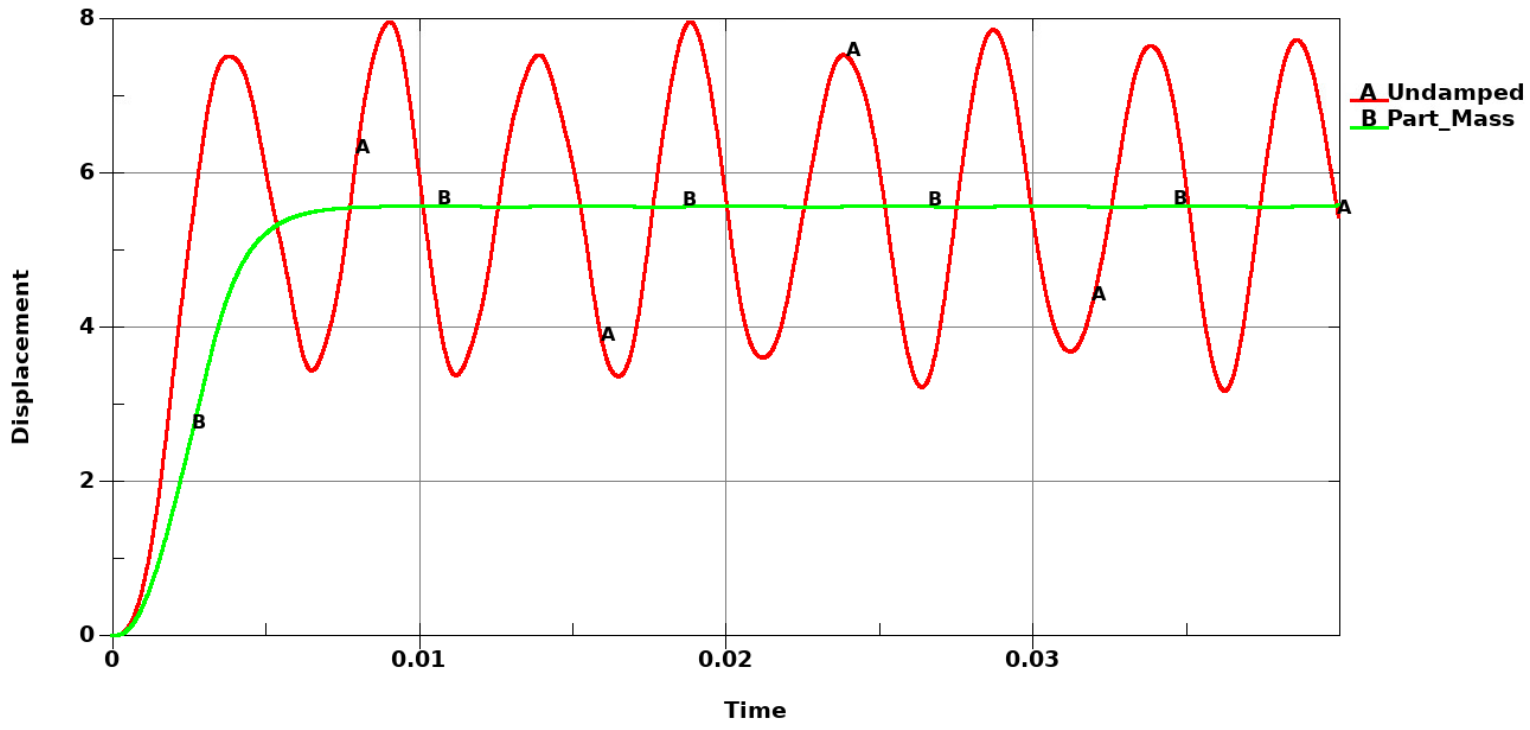
- A car tire is pressurized with an airbag keyword in 0.003 s.
- This causes oscillations with a frequency of approximately 200 Hz.

Node on tire surface



Example – Car tire

- *DAMPING_PART_MASS
  - Damping constant: 2500 (critical damping)
  - Damping only applied during the first 0.008 s (define with load curve)



Damping in explicit Dynamic Relaxation

- In explicit dynamic relaxation the node velocities are reduced each timestep, i.e. the model are damped with a sort of mass damping
- The mass damping factor in explicit DR can be calulcated by:

$$\alpha = \frac{(1 - DRFCTR)}{\Delta t}$$

- Thus, the damping factor in DR is defined by the dynamic relaxation factor and the simulation timestep.

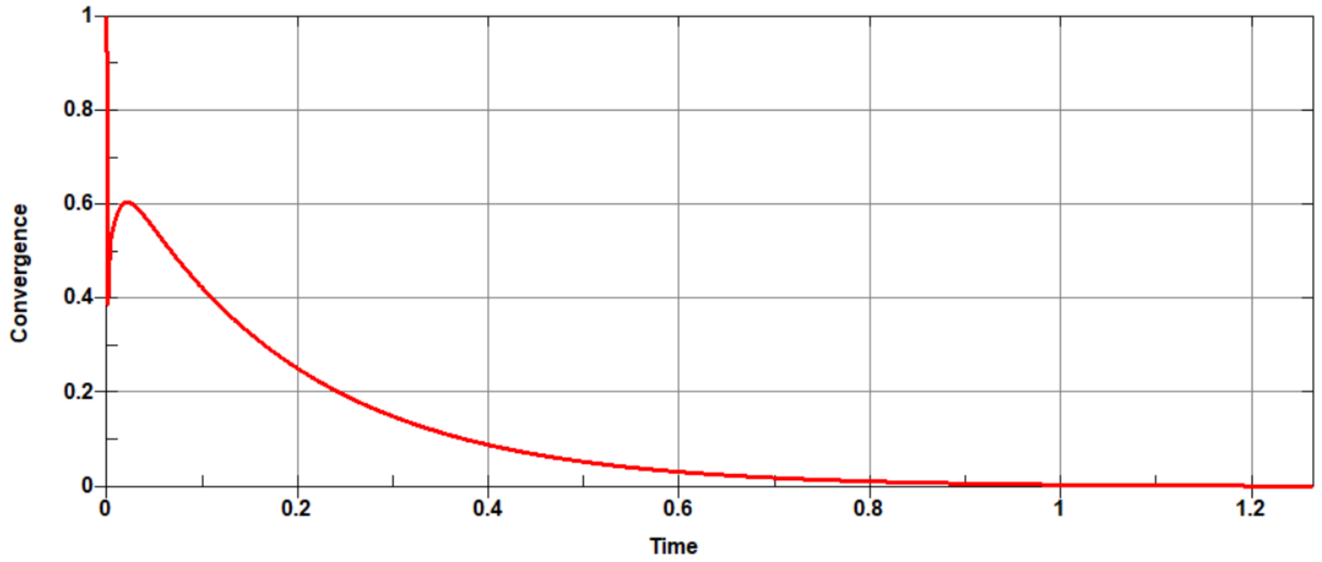
Damping in explicit Dynamic Relaxation

- A pre-bend plate with initial stresses are released

- Could dynamic relaxation be used to find the plate equilibrium?

Damping in explicit Dynamic Relaxation

- Convergence is found but it takes 1.26 s in simulation time.



- What damping factor is used in the dynamic relaxation?

$$\alpha = \frac{(1-DRFCTR)}{\Delta t} = \frac{(1-0.995)}{1.65E-6} = 3030$$

- Is this a reasonable value for this model?

Damping in explicit Dynamic Relaxation

- The eigenmode of interest for the plate has a frequency of 14.1 Hz
- The critical damping would then be:

$$\alpha = 2 * \omega = 2 * 2 * \pi * f = 177$$

- This means that with a damping constant of 3030 the model would be severely overdamped.

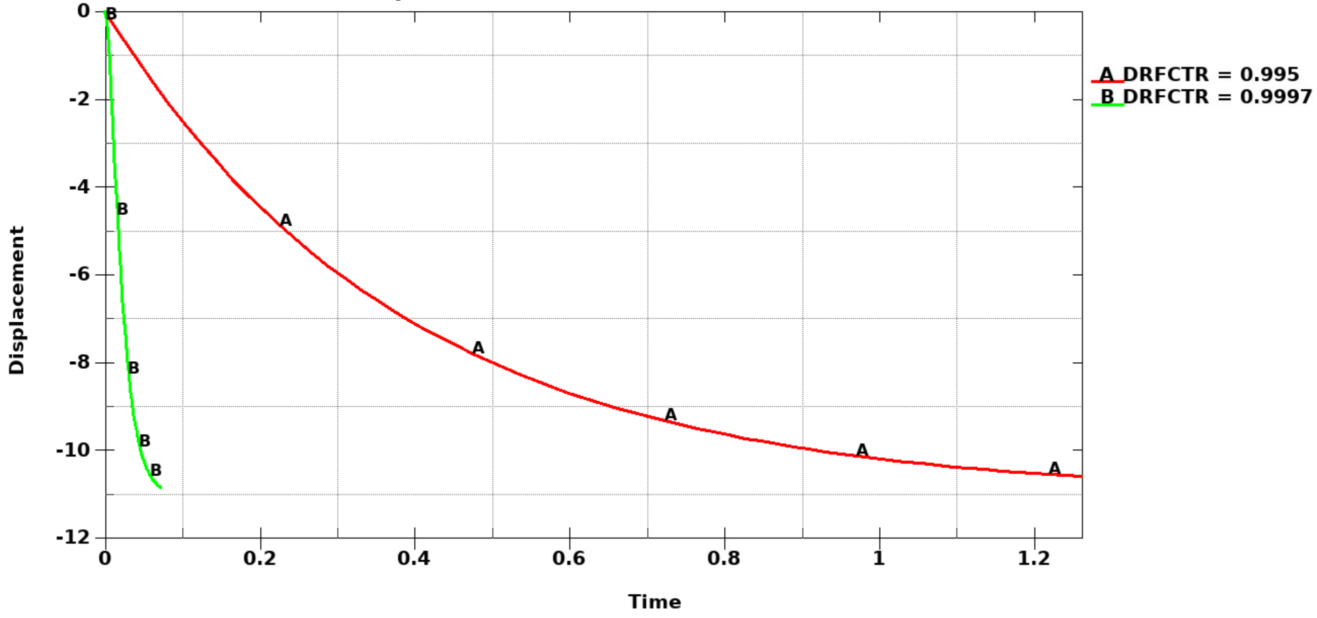
- To change the damping in the model the dynamic relaxation factor need to be changed:

$$\alpha = \frac{(1 - DRFCTR)}{\Delta t} \rightarrow DRFCTR = 1 - \alpha * \Delta t = 0.9997$$

Damping in explicit Dynamic Relaxation

- With the new DRFCTR that corresponds to critical damping the model converges in 0.073 s. Thus 17 times faster than with the nominal value.

Plate end displacement from D3DRLF

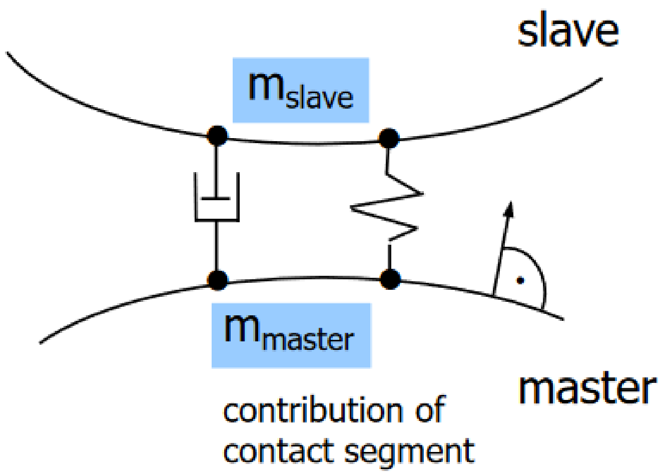


Damping in explicit Dynamic Relaxation

- When using dynamic relaxation to reach steady state, and the model has low frequency deformation modes, a good procedure would be to identify the frequency of interest and adjust the dynamic relaxation factor (DRFCTR).
- A typical loading condition that will experience low frequency deformation modes is gravity load.

Damping in Contacts

- Damping in contacts can be applied with the VDC parameter (Viscous Damping Coefficient). The parameter is found in Card 2 in the contact keyword.
  - VDC = 20 (corresponds to 20 % of critical damping) is recommended
  - VDC = 40-60 is recommended for contacts with soft material

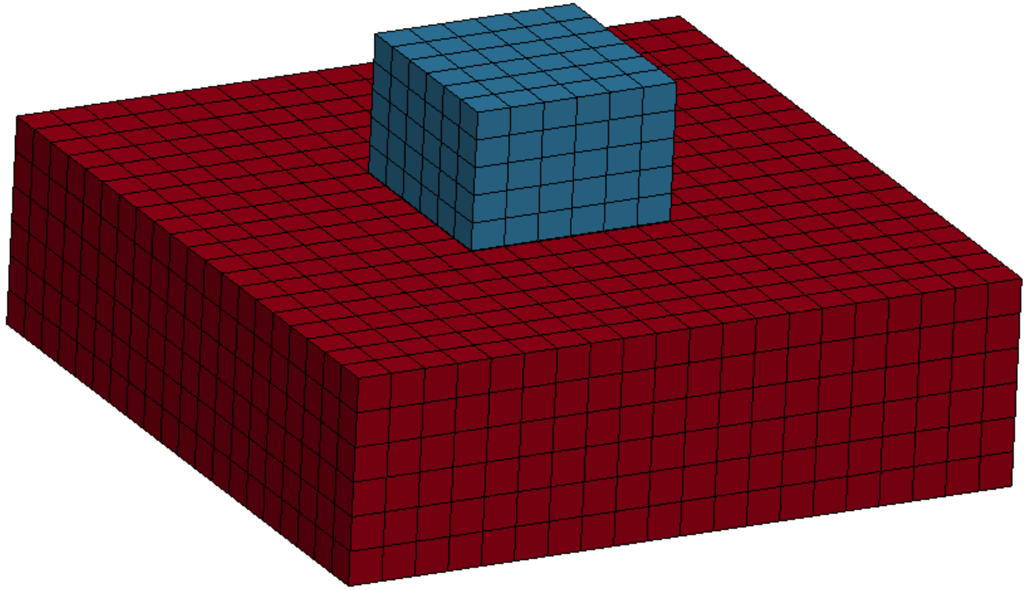


$$\xi = 2m\omega$$

$$\omega = \sqrt{\frac{k(m_{slave} + m_{master})}{m_{slave} \cdot m_{master}}}$$

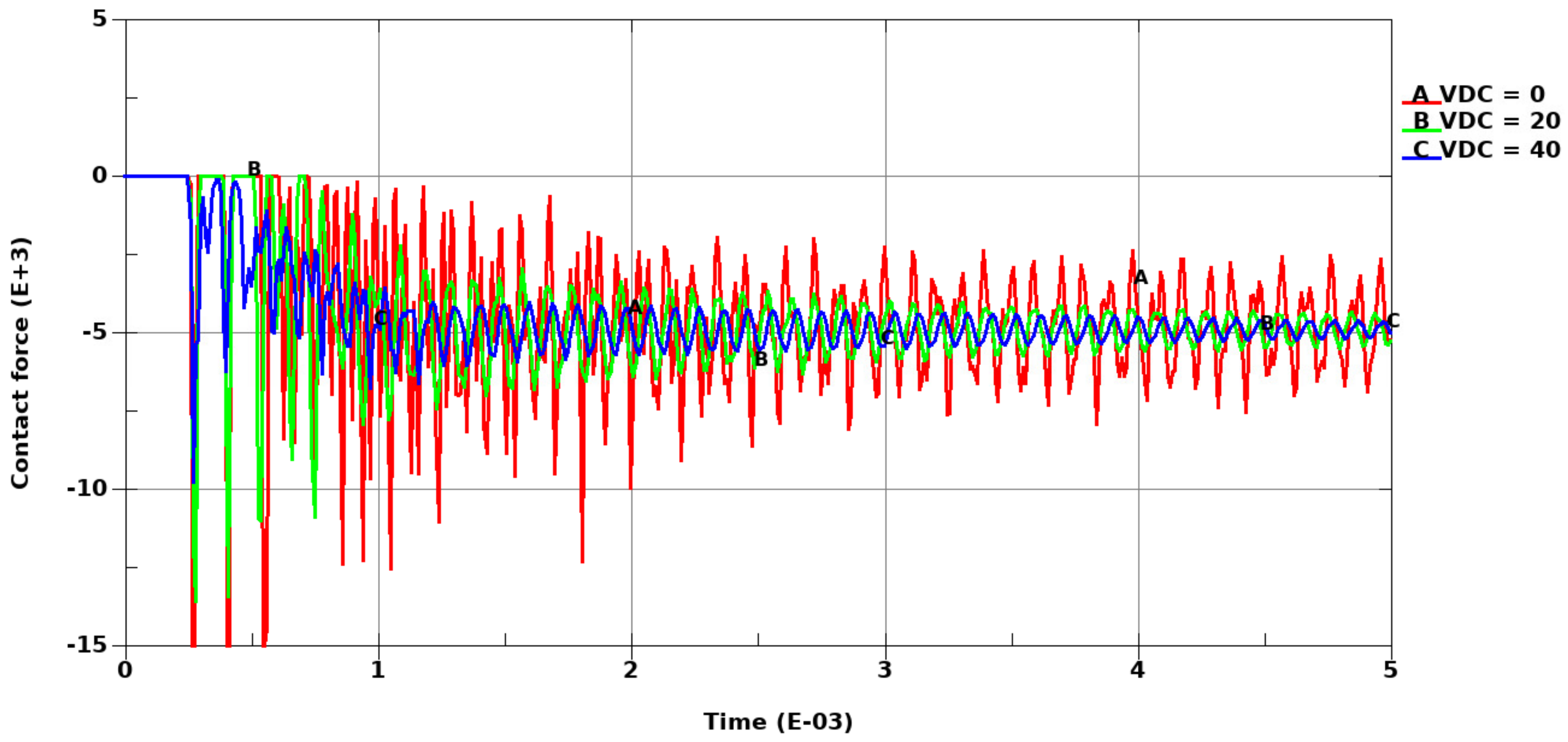
Damping in Contacts

- Two elastic blocks with material properties of steel
- A force is applied to the upper block



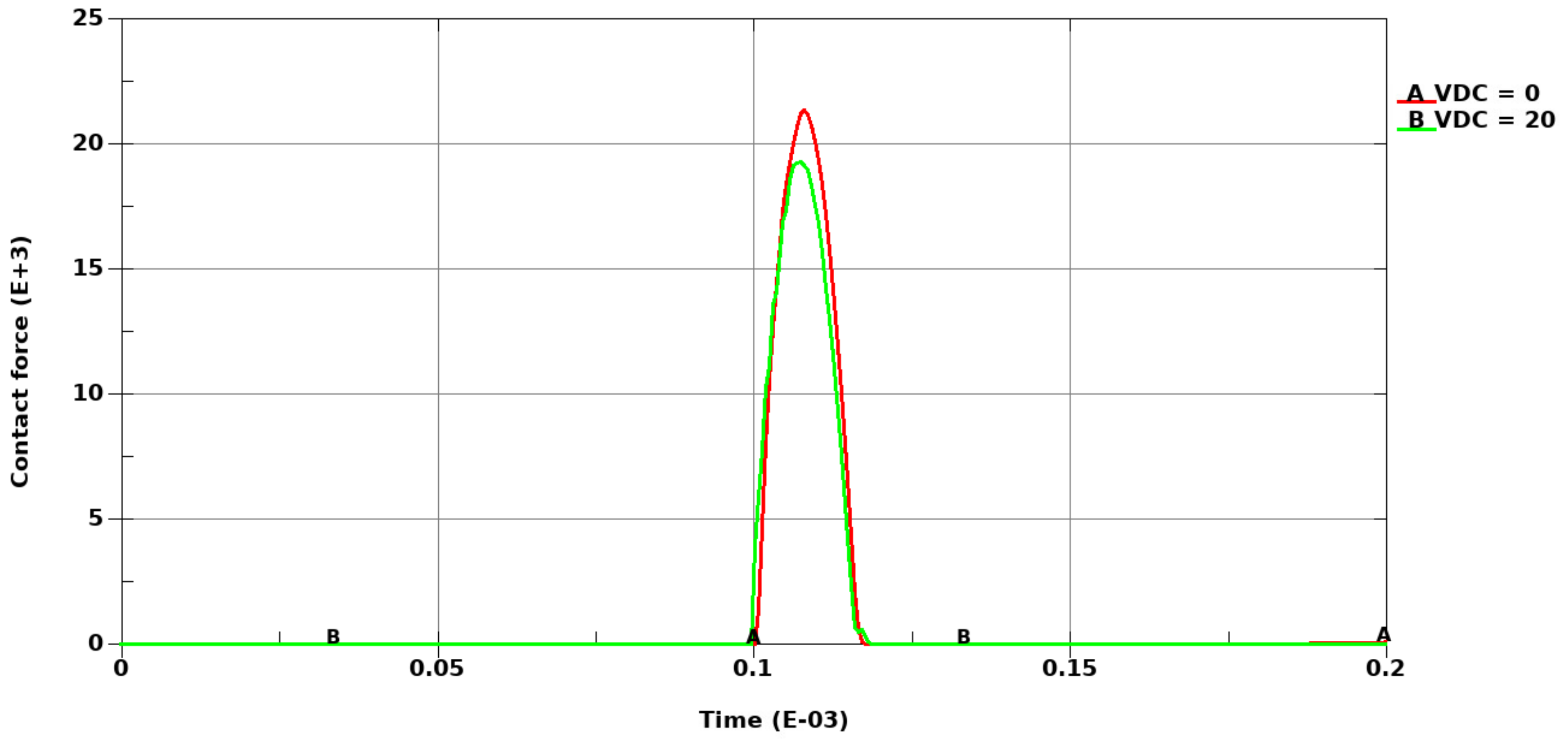
Damping in Contacts

- The oscillations in the contact force are reduced when applying damping in the contact.



Damping in Contacts

- Instead of an applied force the upper block are defined with an initial velocity.
- Applying damping in the contacts decreases some of the kinetic energy in the impact and thus decreases the maximum contact force.



Damping in Material Models

- For some of the material models in LS-DYNA a damping option is available.
- These damping options exists to decrease high frequency oscillations and increase stability in the material.
- Typical material models where damping options are available are:
  - Foams
  - Rubbers
  - Fabrics
- See the manual for suggested values in the damping option for the individual material models.

General recommendations when using Damping

Stiffness damping

- Keyword:
  - *DAMPING_PART_STIFFNESS
  - *DAMPING_FREQUENCY_RANGE_DEFORM
- Use recommended damping coefficients
- Effective for high frequencies
- If the frequency is known, the *DAMPING_FREQUENCY_RANGE_DEFORM could be used.

- Application areas:
  - Impact analyses. Reduce high frequency responses to improve stability in the model.
  - Shock wave analyses. Reduce high frequency responses (stress amplitudes) for fatigue analyses.
  - Could be used to improve convergence in dynamic relaxation for pre-stressing bolts.

General recommendations when using Damping

Mass damping

- Keyword:
  - *DAMPING_GLOBAL
  - *DAMPING_PART_MASS
  - *DAMPING_FREQUENCY_RANGE
- If fully damping is wanted, set the damping constant to critical damping (not applicable for DAMPING_FREQUENCY_RANGE).
- Effective for low frequencies
- Will damp rigid body motions!!

- Application areas:
  - Quasi static analyses. Damp out unwanted low frequency oscillations.
  - Preloads. Apply damping during preloads and then remove when preload is completed.
  - Dynamic Relaxation uses mass damping. Check the damping ratio used in DR to avoid overdamping and thus long time to convergence.

Thank you!

Your LS-DYNA distributor and more