MPM Simulation of Acoustic Behavior

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Motivations & Approach

Motivations:

- A building/assembly wall needs to meet mechanical requirements and also to be good in acoustic performance (reducing noise attenuation)
- Typically it is too late once a structure is already built (in buildings, typically can only add carpet on the floor)
- Simulation tools can help to predict noise attenuation in building materials (design)

Approach:

- Use MPM to simulate acoustic (stress wave) behavior and compare to exited typical assembly wall data (as standard for wood construction)
  - ✓ Need for both solid and air
- Simulate MPM structures (structures with rooms--solid members and air) and compare with exited data

Solid Wood Properties (Strand)

(Previous MPM workshop)

1. Orthotropic material, plane strain
2. Hill plasticity criterion, and power-law work hardening term

$$f = \sqrt{\left(\frac{\sigma_x}{\sigma_x^Y}\right)^2 + \left(\frac{\sigma_y}{\sigma_x^Y}\right)^2 + \left(\frac{\sigma_z}{\sigma_z^Y}\right)^2 - F\sigma_y\sigma_z - G\sigma_x\sigma_z - H\sigma_x\sigma_y + \left(\frac{\tau_{xy}}{\tau_{xy}^Y}\right)^2} - (1 + K\varepsilon_p^n)$$

- where σ_i and τ_{xy} are the normal and shear stresses
- σ_i^Y is the tensile yield stress
- τ_{xy}^Y is the shear yield stress in the material's x-y plane,
- ε_p is plastic strain
- n and K are hardening parameters

$$F = \frac{1}{(\sigma_y^Y)^2} + \frac{1}{(\sigma_z^Y)^2} - \frac{1}{(\sigma_x^Y)^2}, \quad G = \frac{1}{(\sigma_z^Y)^2} + \frac{1}{(\sigma_x^Y)^2} - \frac{1}{(\sigma_y^Y)^2}, \text{ and } H = \frac{1}{(\sigma_x^Y)^2} + \frac{1}{(\sigma_y^Y)^2} - \frac{1}{(\sigma_z^Y)^2}$$

> Yielding occurs when $f = 0$

Solid Wood Property Values (Strand)

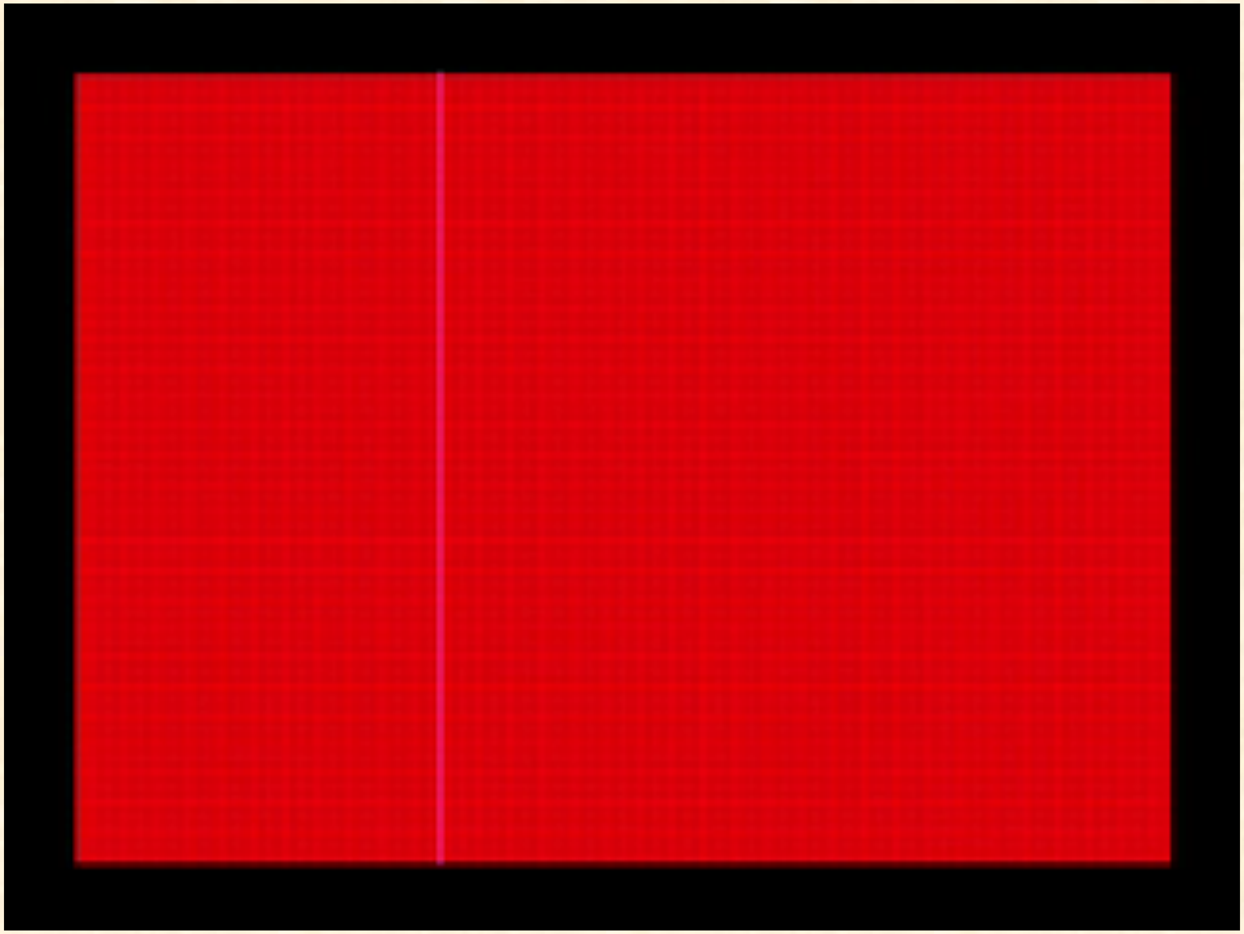
(Previous MPM workshop)

Property in MPa	Unmodified Strands	VTC Strand
E_L	9936	24311
E_R	914	2153
E_T	427	1005
G_{RL}	745	1616
G_{TL}	686	1486
G_{RT}	109	235
μ_{RL}	0.028	0.028
μ_{TL}	0.017	0.017
μ_{TR}	0.33	0.33
σ_L(yield)	∞	∞
σ_R(yield)	5	5
σ_T(yield)	5	5
σ_{RT}(yield)	2.5	10

VTC: Viscoelastic Thermal Compression (densified wood for higher properties)

Reflecting Pulse for Two Materials

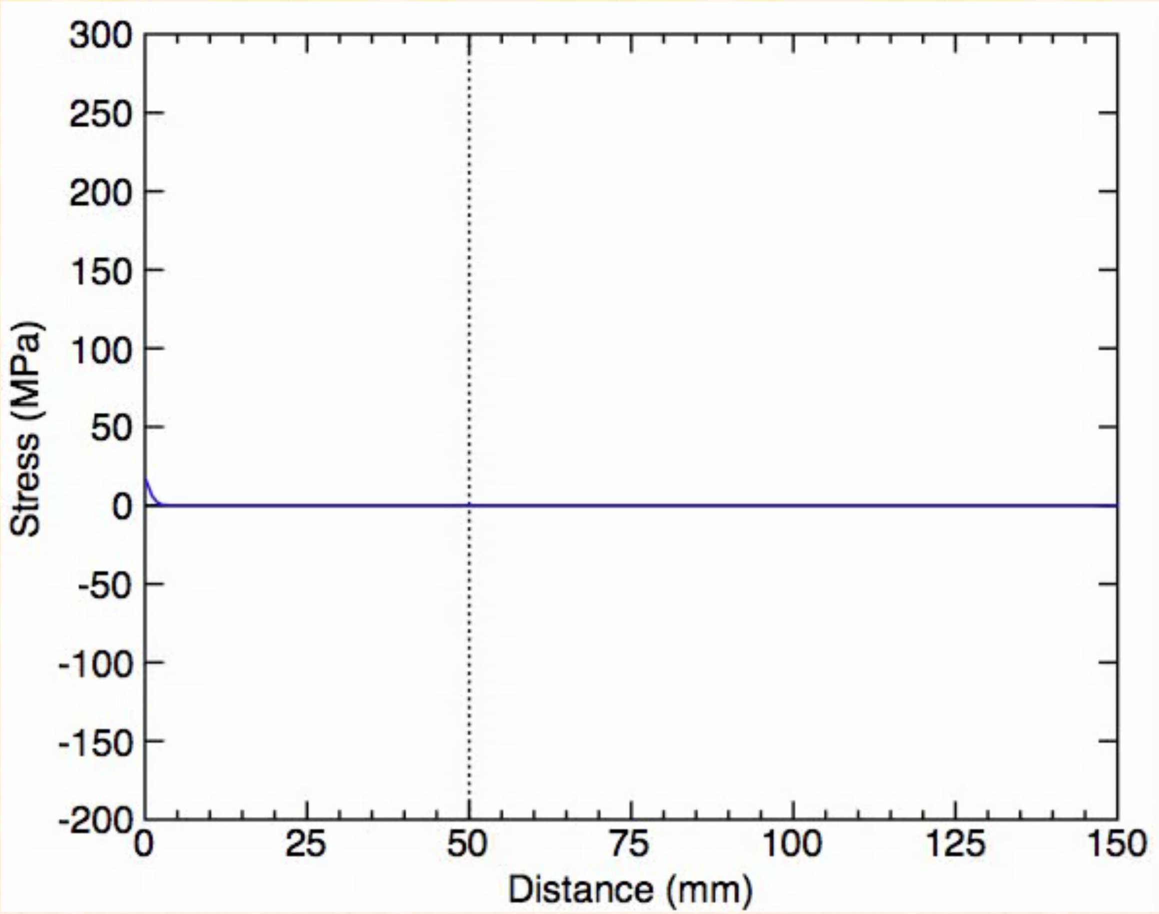
Reflecting pulse by square wave for identical isotropic materials at an imperfect interface



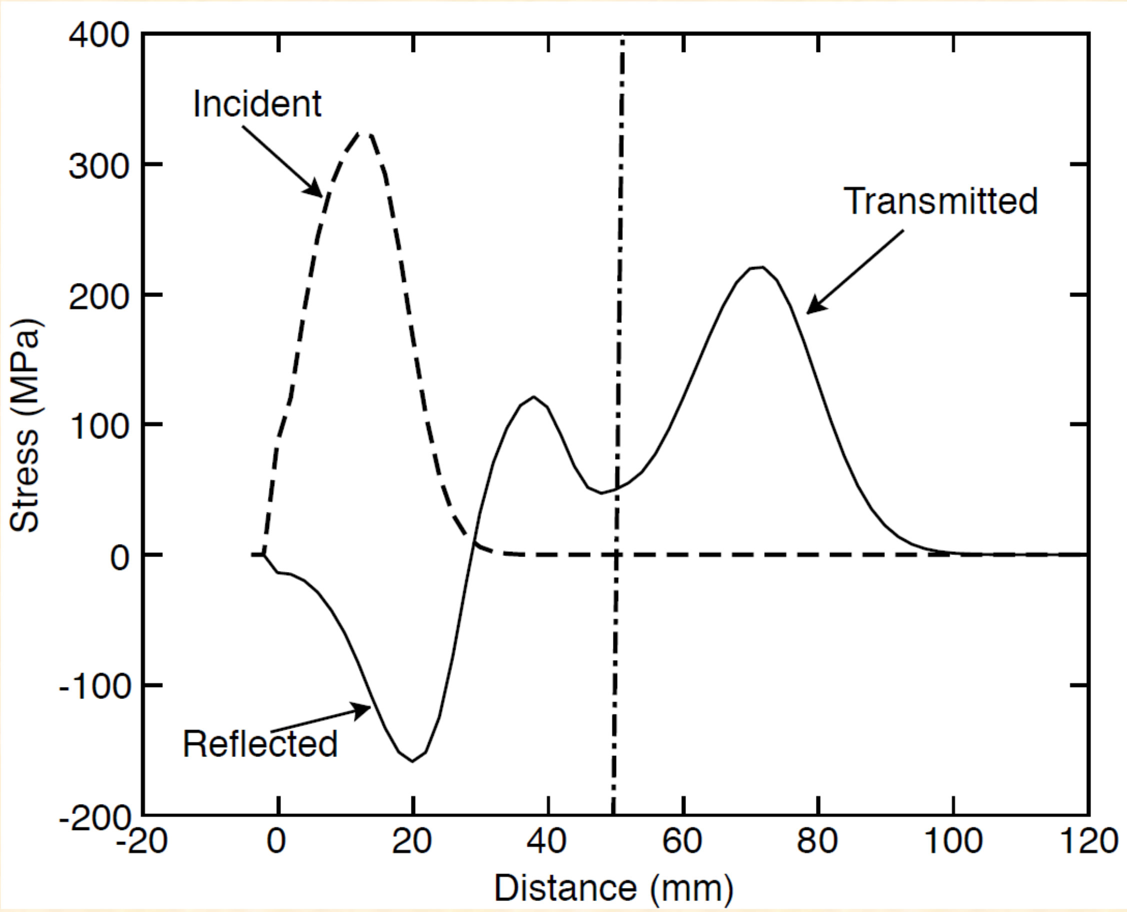
See John A. Nairn, "Numerical Implementation of Imperfect Interfaces," *Computational Materials Science*, **40**, 525-536 (2007) and J.A. Nairn, "Modeling Imperfect Interfaces in the Material Point Method using Multimaterial Methods," *Computer Modeling in Eng. & Sci.*, in press (2013).

Movement of Stress Wave

Reflecting pulse by square wave for isotropic materials

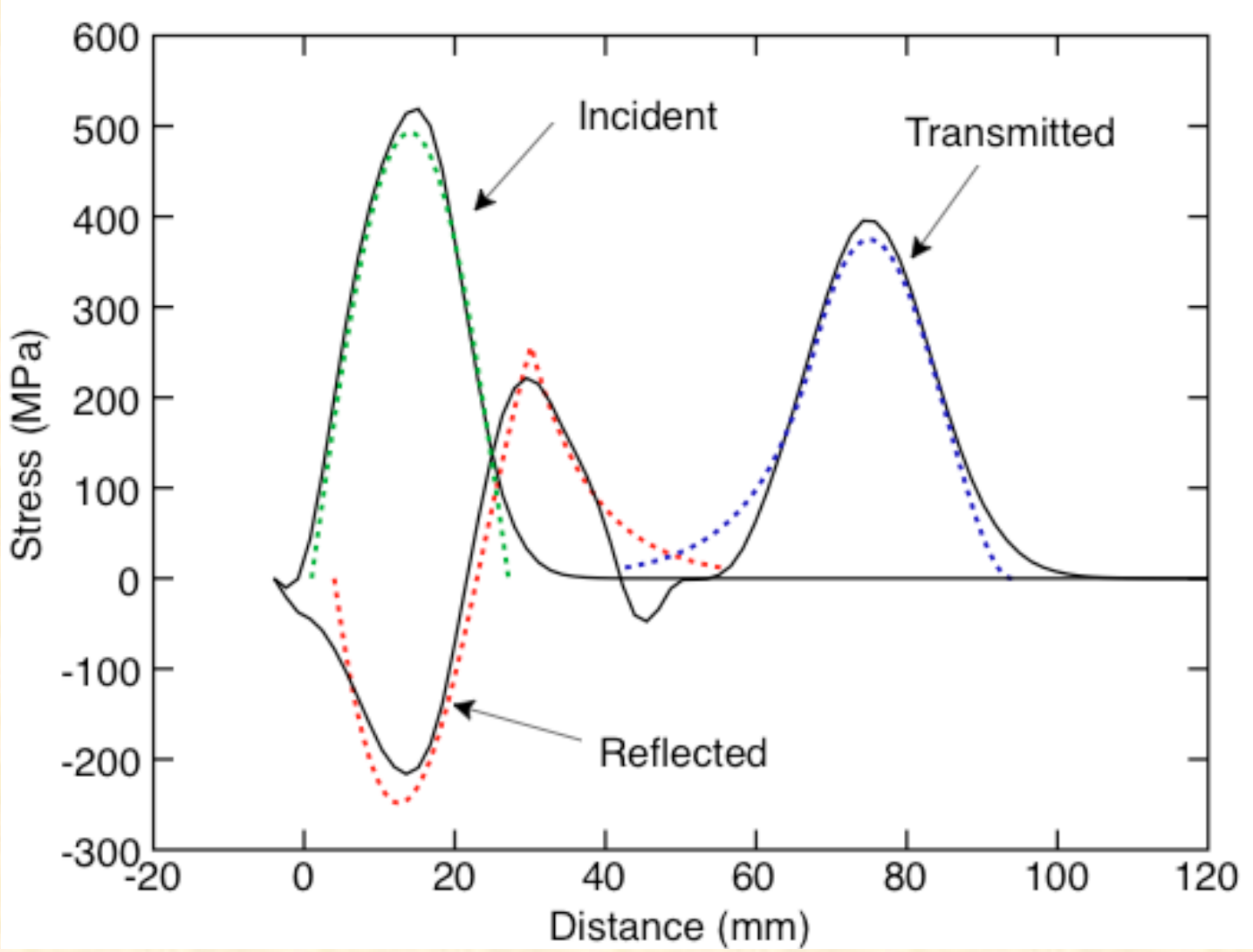


Movement of Stress Wave (Cont’n)



Square wave of stress versus distance at different time

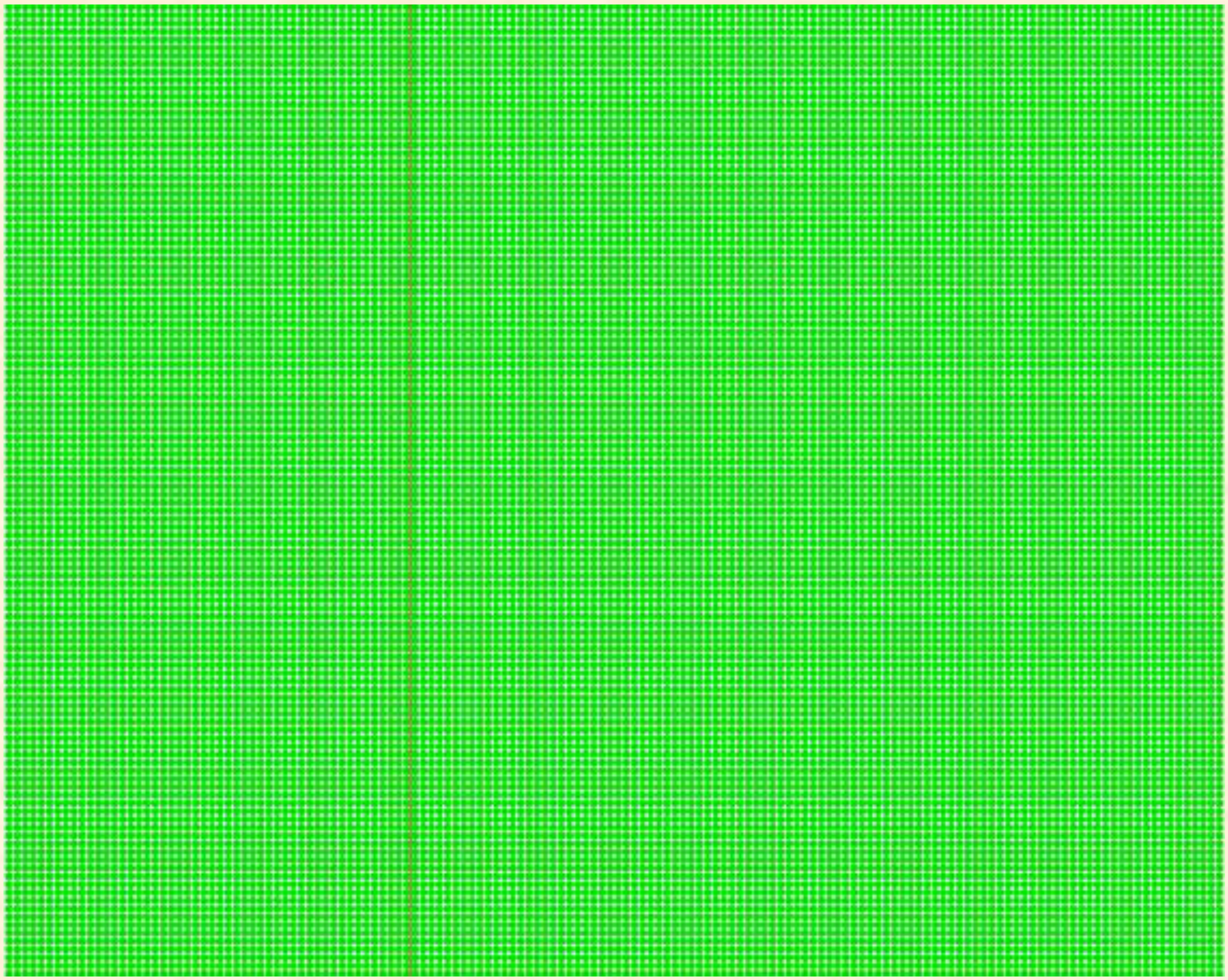
Analytical Validation



Analytical Solution: Dashed Line

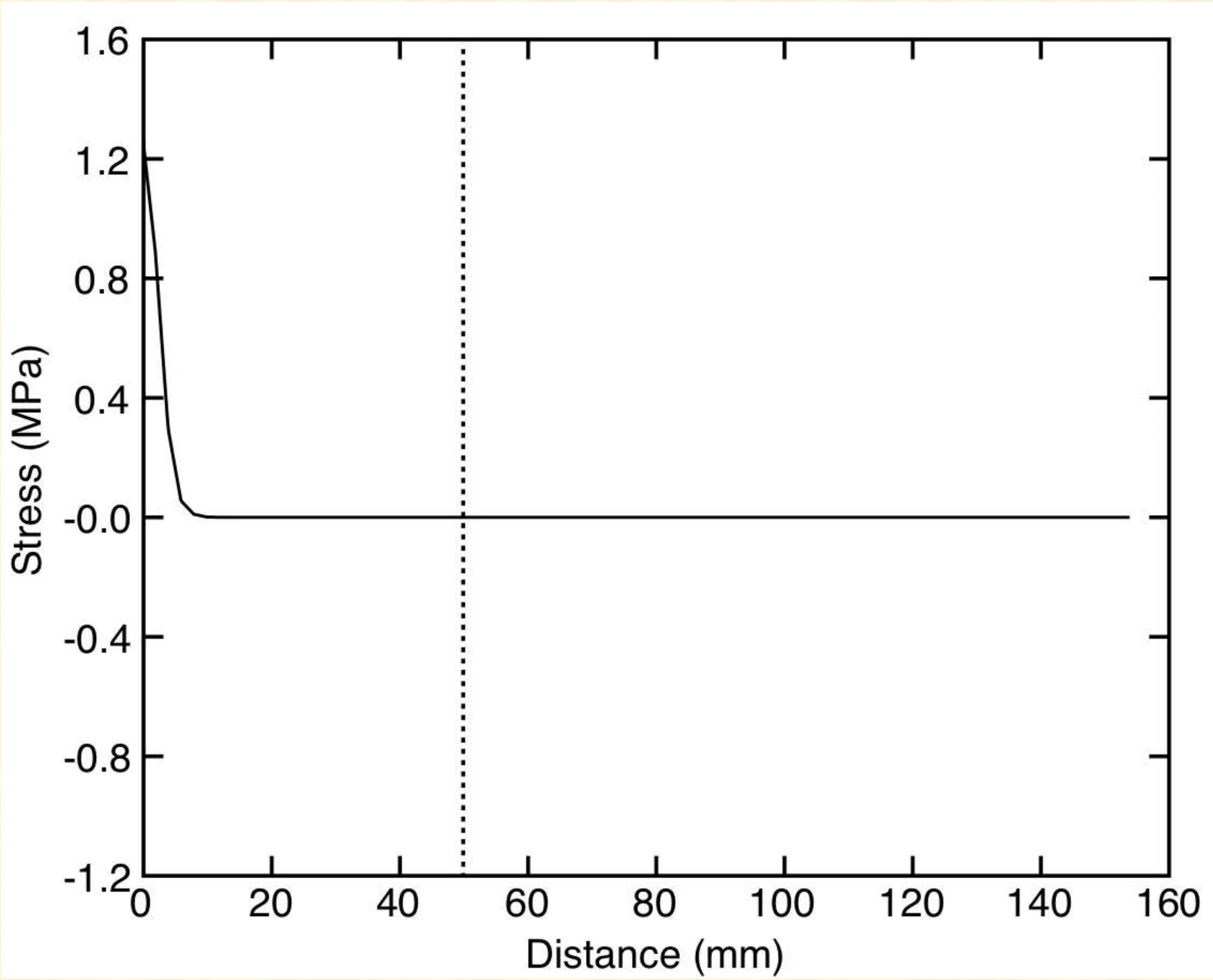
Reflecting Pulse for Two Materials

Reflecting pulse by square wave for identical orthotropic materials (wood) at an imperfect interface



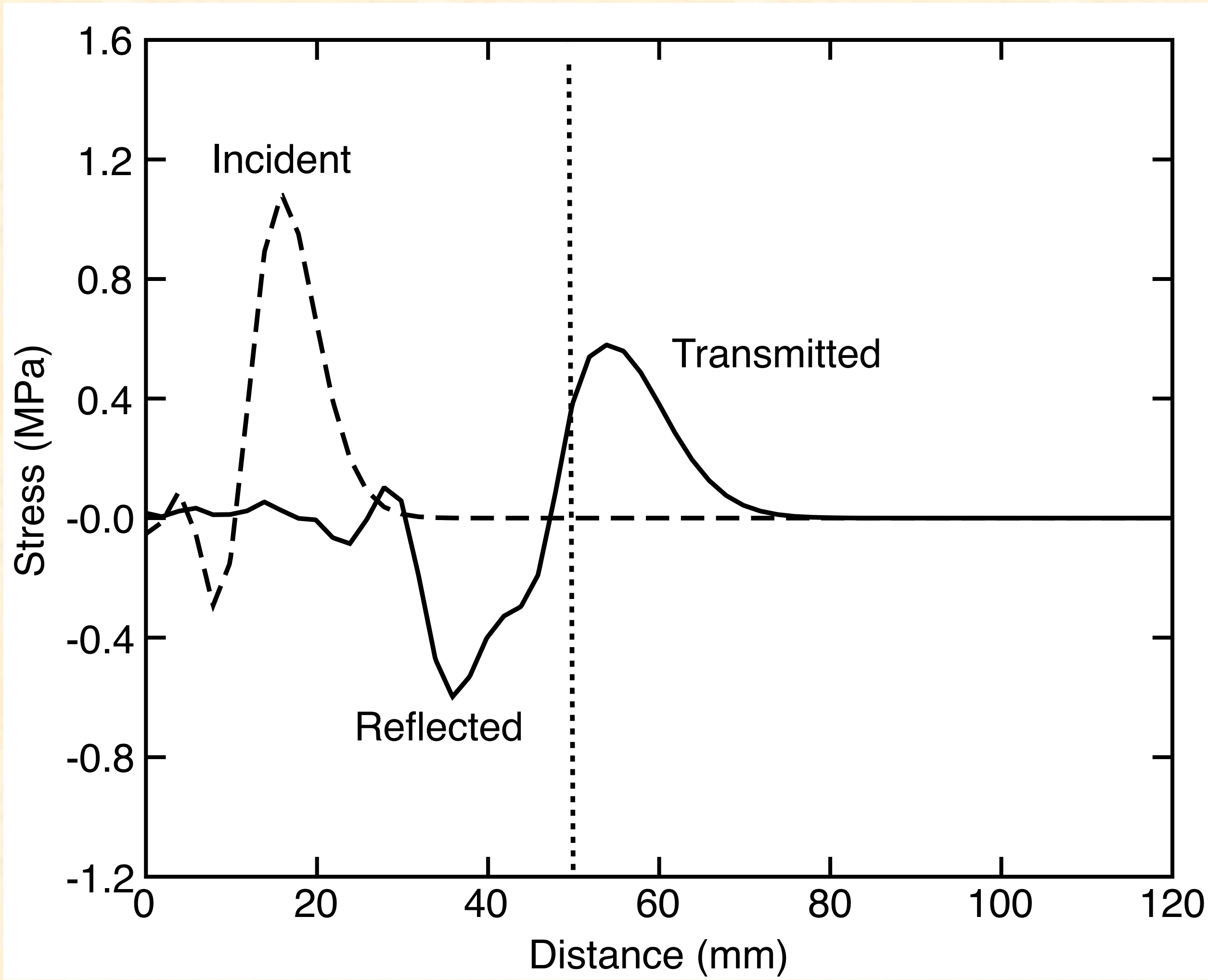
Movement of Stress Wave

Reflecting pulse by square wave for orthotropic materials (wood)



Movement of Stress Wave

Reflecting pulse by square wave for orthotropic materials (wood)



Constitutive Equation

- Ideal gas, as an isotropic hyperelastic material, plane strain

$PV=nRT$ P is pressure T temperature in K

$PV/V=mkRT/V$ $P=\rho TkR$

$P=P_0(\rho/\rho_0)(T/T_0)$

$P=J^{-1}P_0\ T/T_0$ $J=V/V_0$ J is determinant of the deformation tensor

P is stored in the normal stresses $\sigma_{xx} = \sigma_{yy} = \sigma_{zz} = -P$

Constitutive Equation (Cont'n)

- Small Strain:

$PV=P_0V_0$ $P/P_0=V_0V$ $P_0/P=V/V_0=(V_0+\text{del } V)/V_0=1+(\text{del } V/V_0)=1+\varepsilon V$

$P=P_0\{1/(\varepsilon_{11}+\varepsilon_{22}+\varepsilon_{33})\}*(T/T_0)$

- Large Strain:

J is determinant of the deformation tensor

$V/V0=J=\det F$

F deformation gradient

$F_{n+1}=f\ F_n$

$J_n+1=\text{def } f\ J_n$

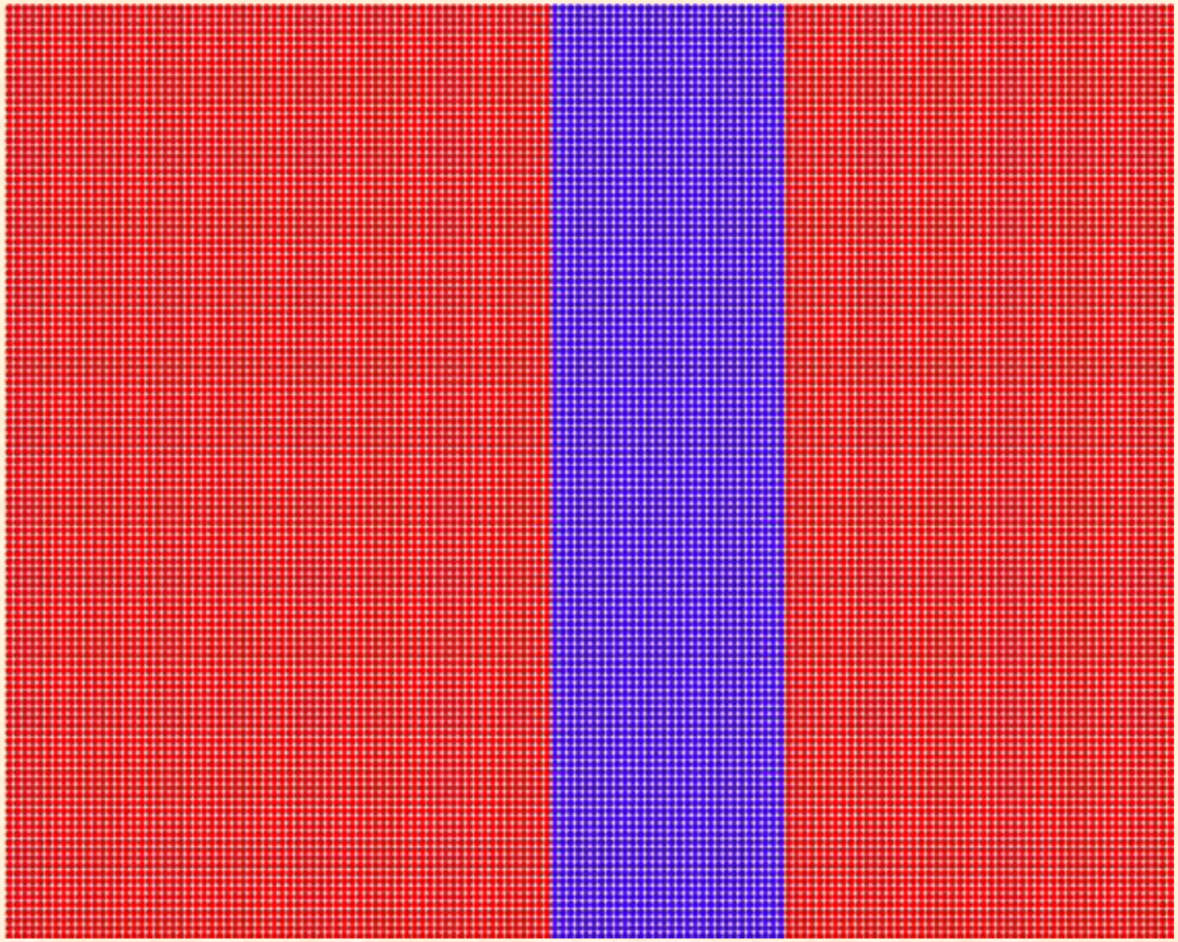
$P_{n+1}=P_0[(T_{n+1})/T_0]J_{n+1}$

Constitutive Equation (Cont'n)

- The possible input properties are:
  - <P0>0.1013</P0>
    The reference pressure (in MPa) at reference temperature and reference density.
  - <T0>273.15</T0>
    The reference temperature (in Kelvin)
  - <rho>0.0013</rho>
    The reference density (in g/cm^3) at reference temperature.

Movement of Pulse in Solid and Air

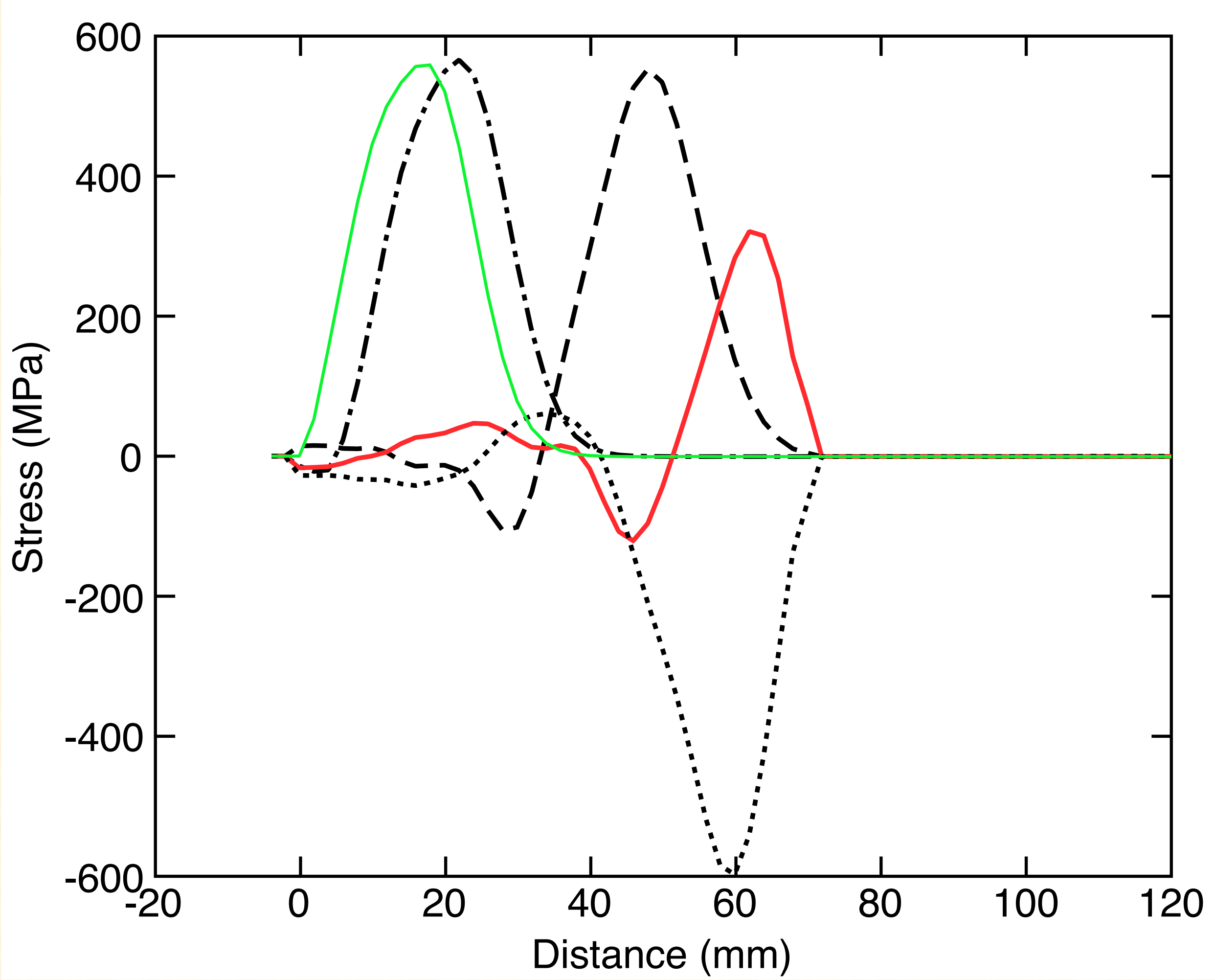
Isotropic and air in middle section



Moving much slower in air

Movement of Stress Wave

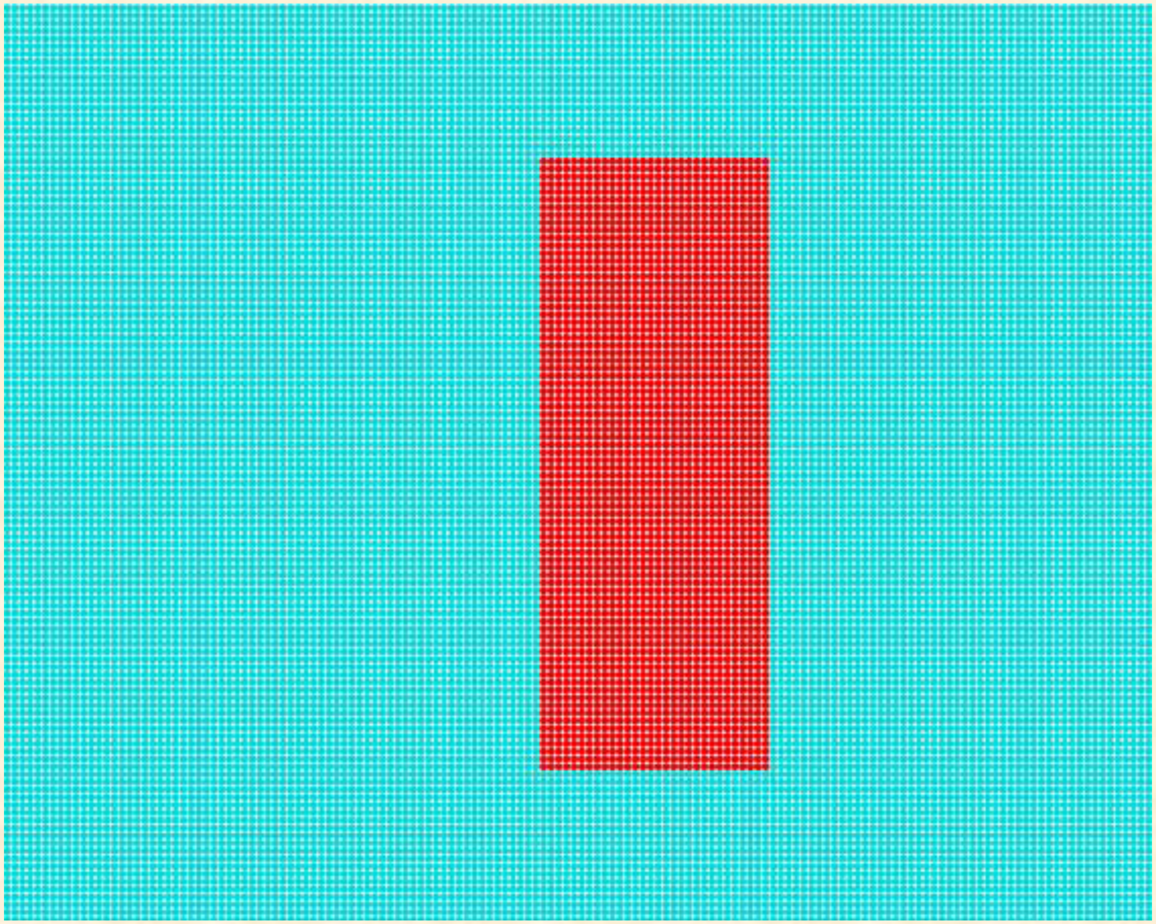
Isotropic and air in middle section



Moving much slower in air

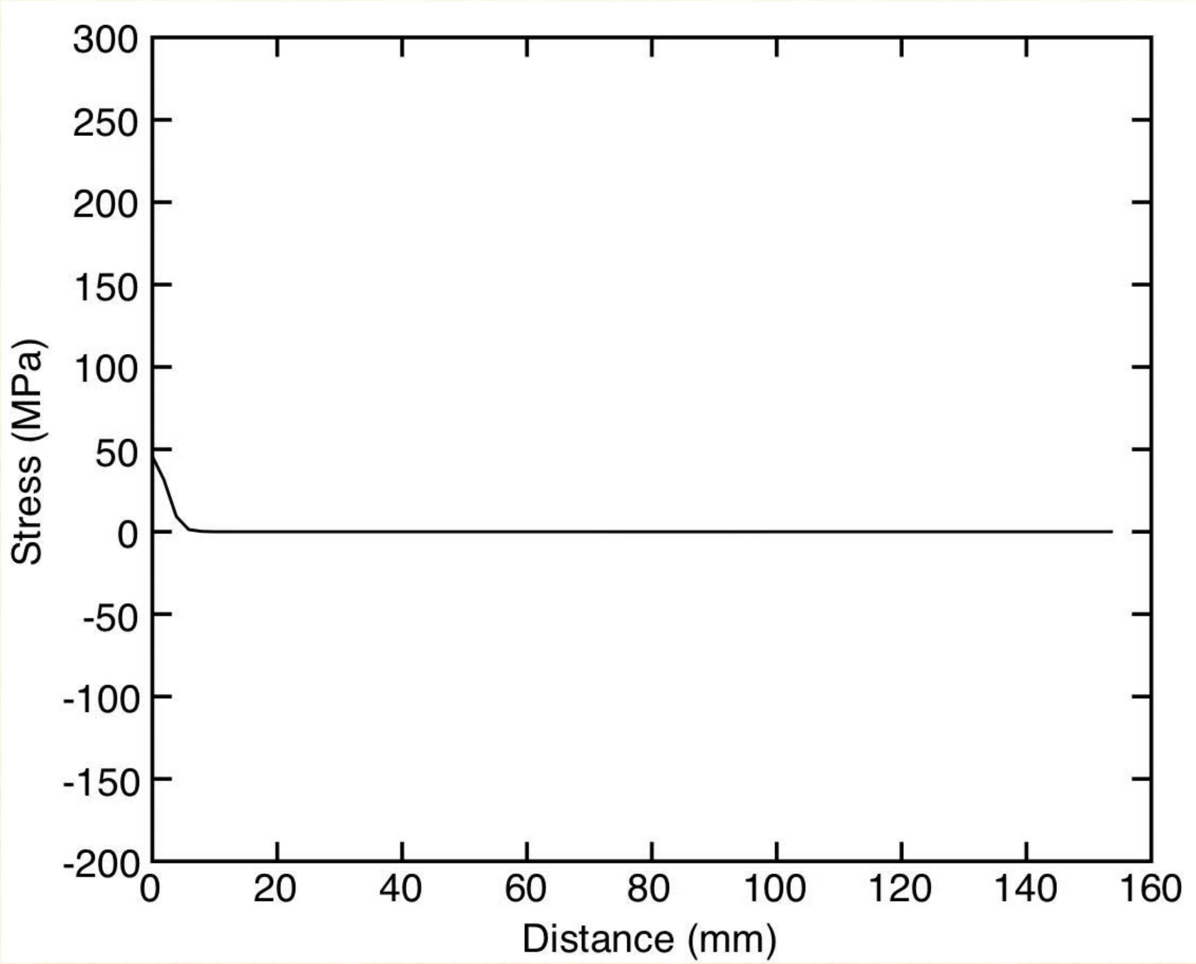
Movement of Pulse for Isotropic

Isotropic with wave wrapping around air gas



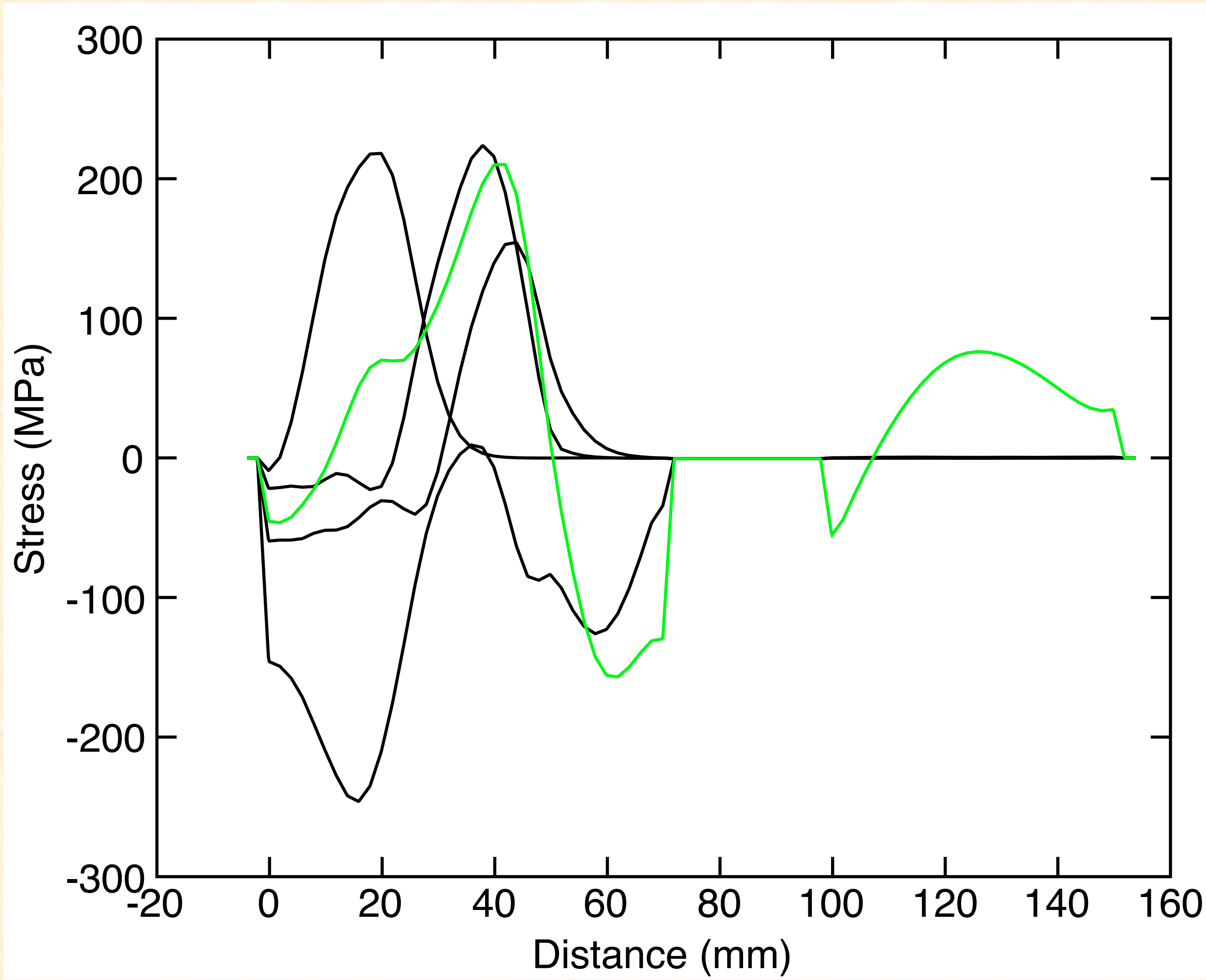
Movement of Stress Wave

Isotropic with wave wrapping around air gas



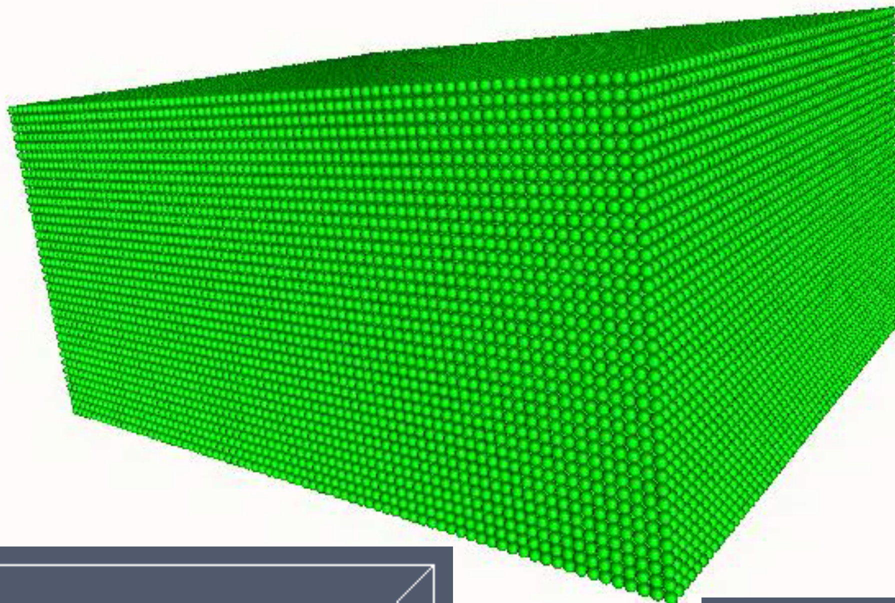
Movement of Stress Wave

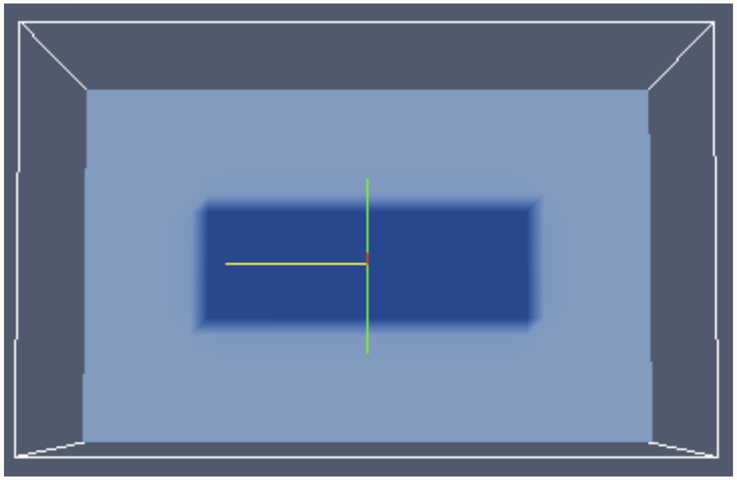
Isotropic with wave wrapping around air gas

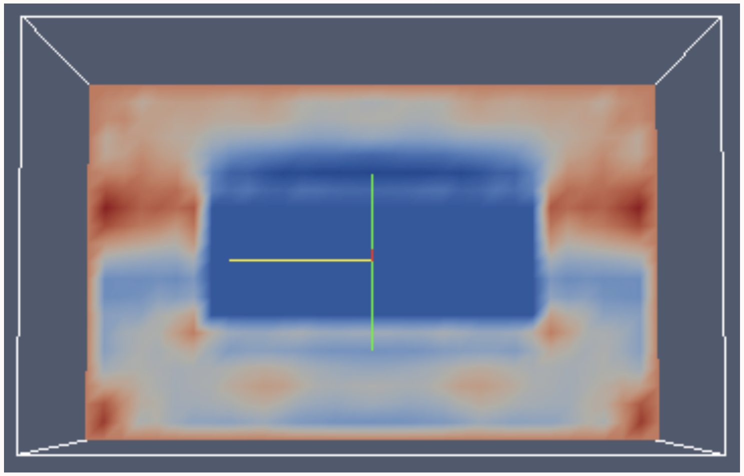


Movement of Pulse for Isotropic

Isotropic and air in center with applying wave at along edge for 3D

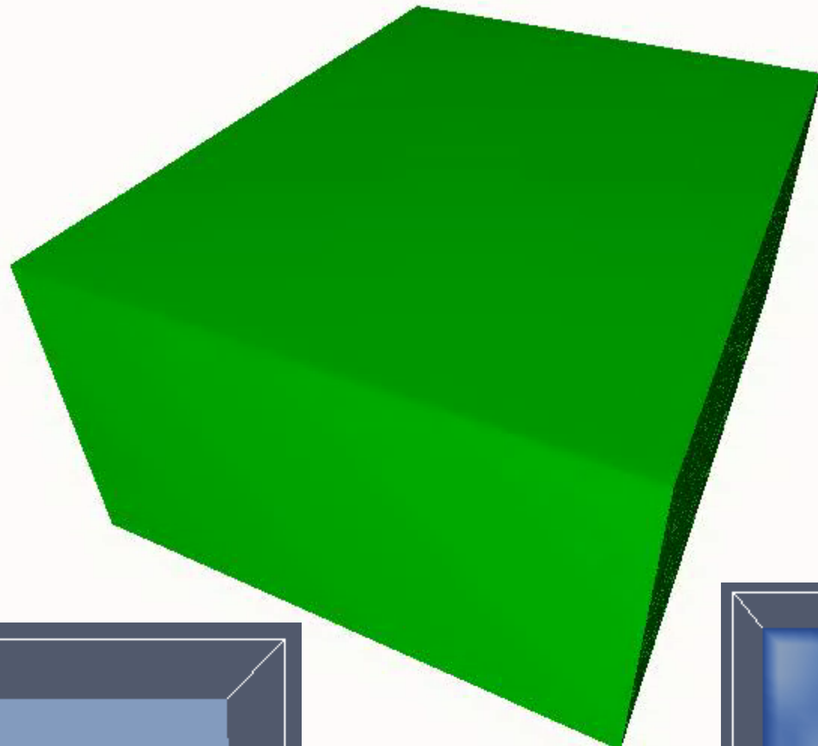


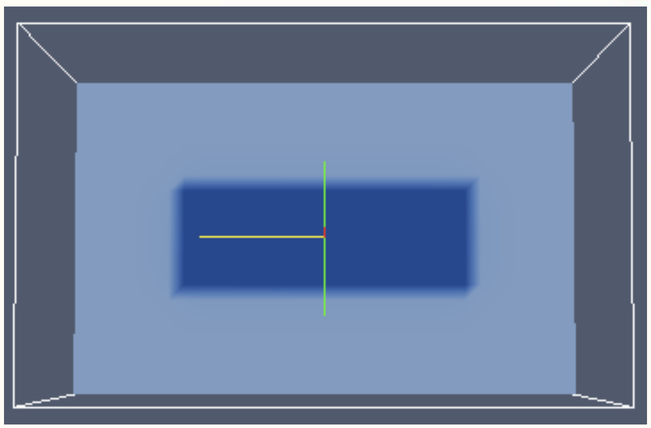


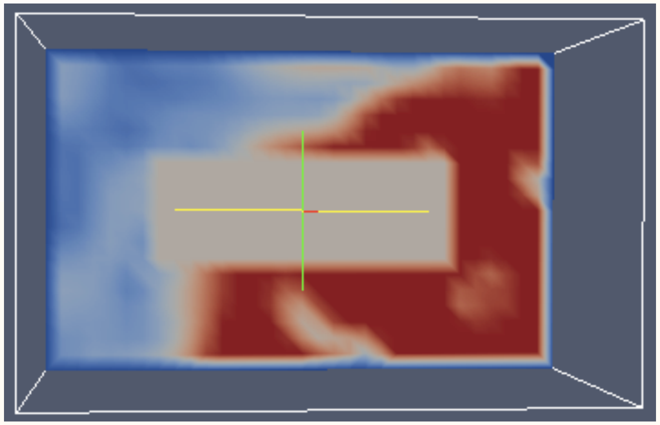


Movement of Pulse for Isotropic

Isotropic and air in center with applying wave at corner edge for 3D

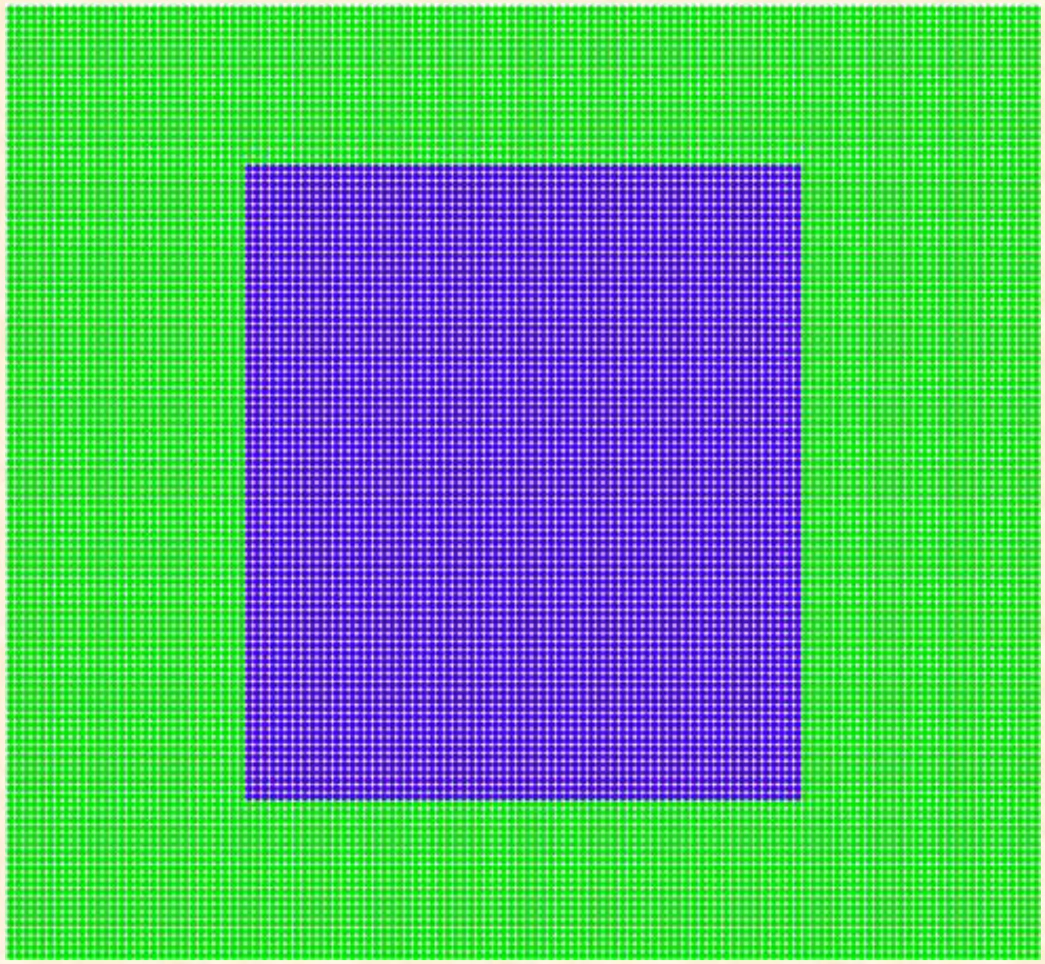






Movement of Pulse for Orthotropic Materials

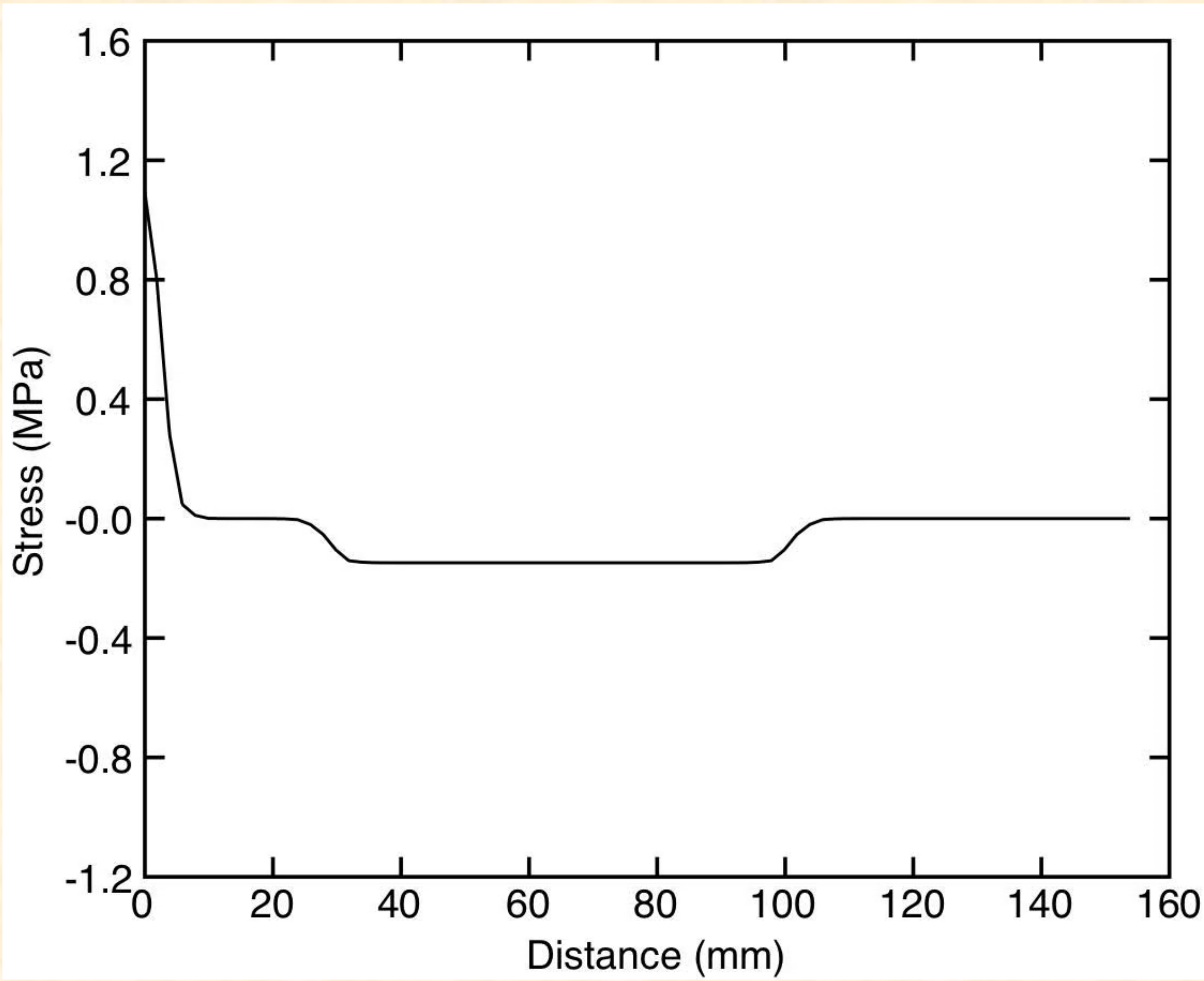
Orthotropic materials with wave wrapping around air gas



Wave transmission in wood is much more complex

Movement of Stress Wave for Orthotropic Materials

Orthotropic materials with wave wrapping around air gas



Conclusions

- New material developed that mimics air gas is possible to simulate acoustic (stress wave) behavior in 2D and 3D
- Simulations are possible to show incident, transmitted and reflected waves
- Incident, transmitted, and reflected waves in MPM were comparable to analytical solution (isotropic)
- Wave transmission in wood is much more complex than other isotropic materials
- Simulation tools are very important for predicting noise attenuation/wave movement (for inclusion problems)

Acknowledgements

- Prof. John Nairn
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Thank you for your attention