Simplified Modelling Method of Impact Damage for Numerical Simulation of Lamb Wave Propagation in Quasi-isotropic Composite Structures

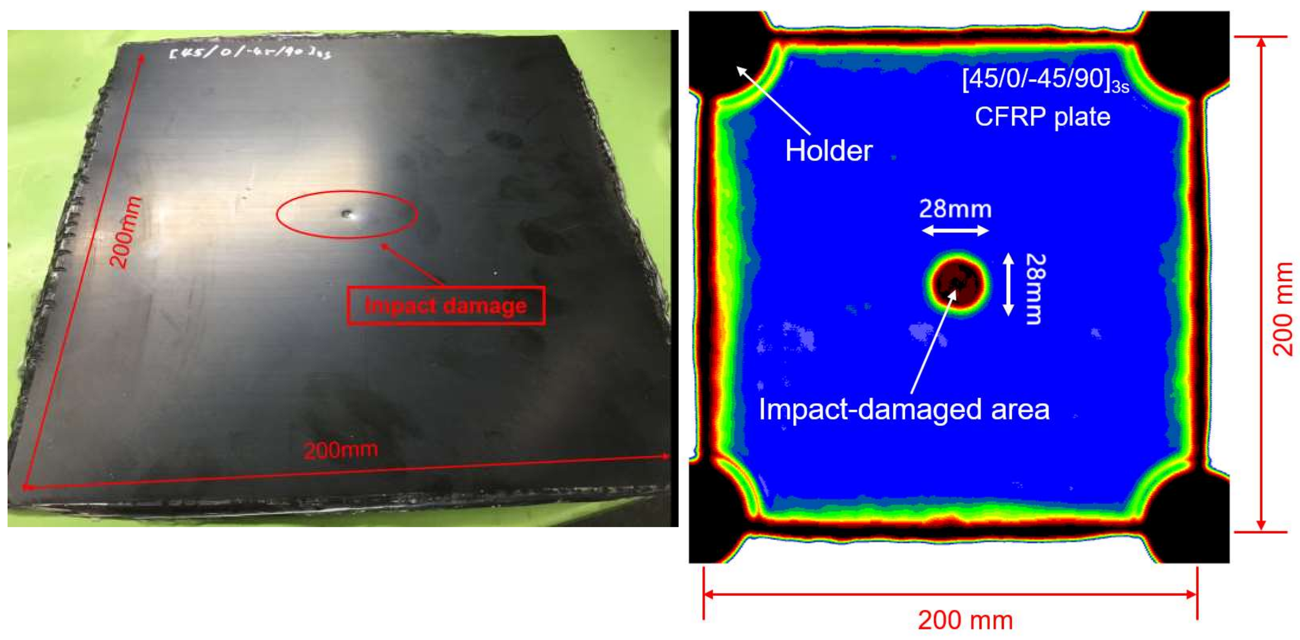
Research Background

The structural components suffer from impact damage, which is one of the most fatal damage for composites caused by a collision with objects or tool drops. Therefore, we are developing health monitoring systems using ultrasonic Lamb waves to detect impact damage in CFRP structures. In order to improve the system performance, FEM simulation is helpful because the wave propagation behavior in the structures can be clarified. However, an impact damage is complex to be modeled precisely because it consists of multiple microscopic damages. Hence, in this research, we attempt to establish a simplified modeling method of the impact damage.

Investigation of Impact Damage

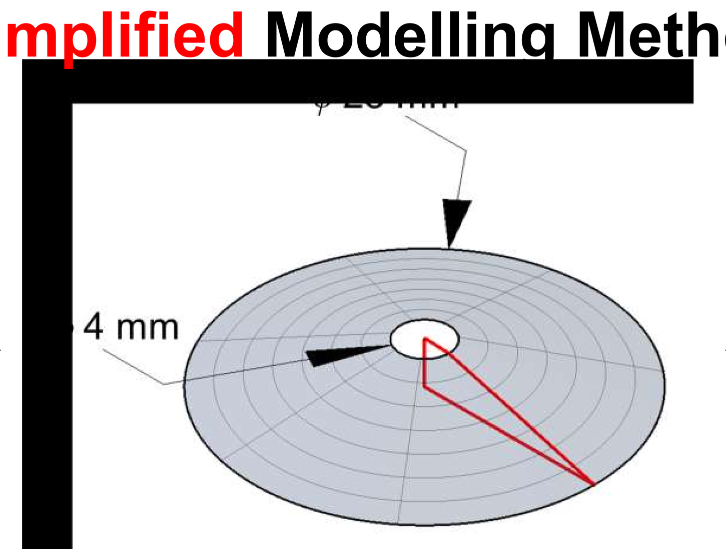
CFRP quasi-isotropic laminates (T700S/2500, $[45/0/-45/90]_{3s}$) with 200mm in length and width and 3.4mm in thickness.

CFRP with an Impact Damage



Dent size : 2 mm. C-scan observation : 14 mm.

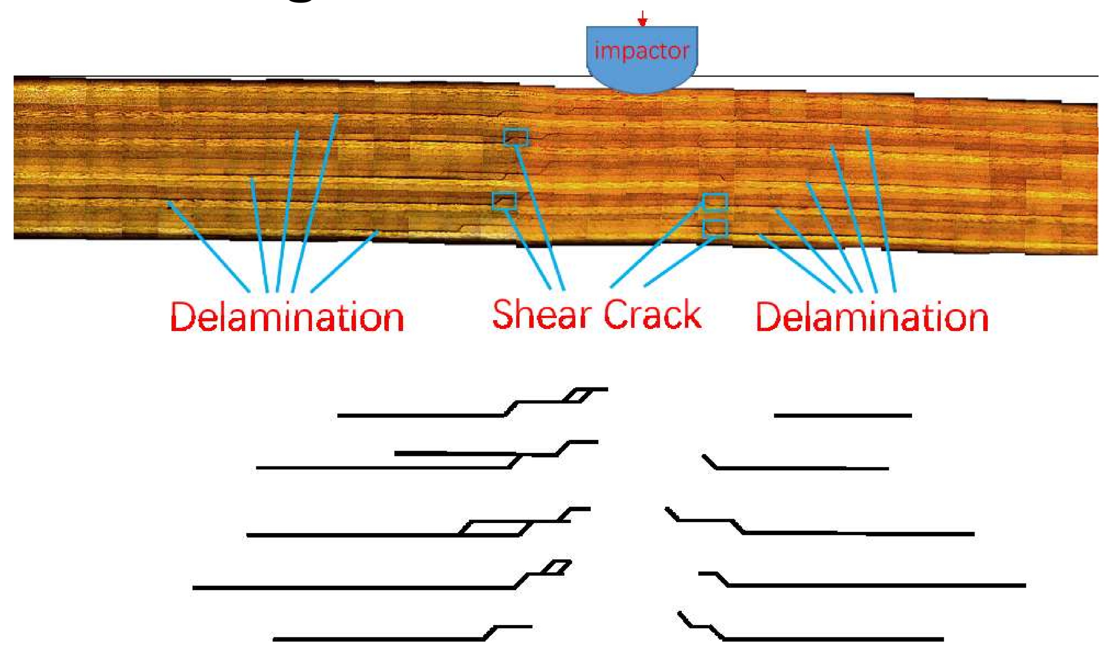
Simplified Modelling Method



Impact-damaged area :

- Homogenous
- Quasi-isotropic
- Stiffness degradation
- Frustum of a cone shape

Damage Observation



Delamination is the dominate damage forms.

Theoretical Assumption of Stiffness Degradation

Stiffness Matrix

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & & & \\ & C_{11} & C_{13} & & & \\ & & C_{33} & & & \\ & & & C_{44} & & \\ & & & & C_{44} & \\ & & & & & C_{66} \end{bmatrix}$$

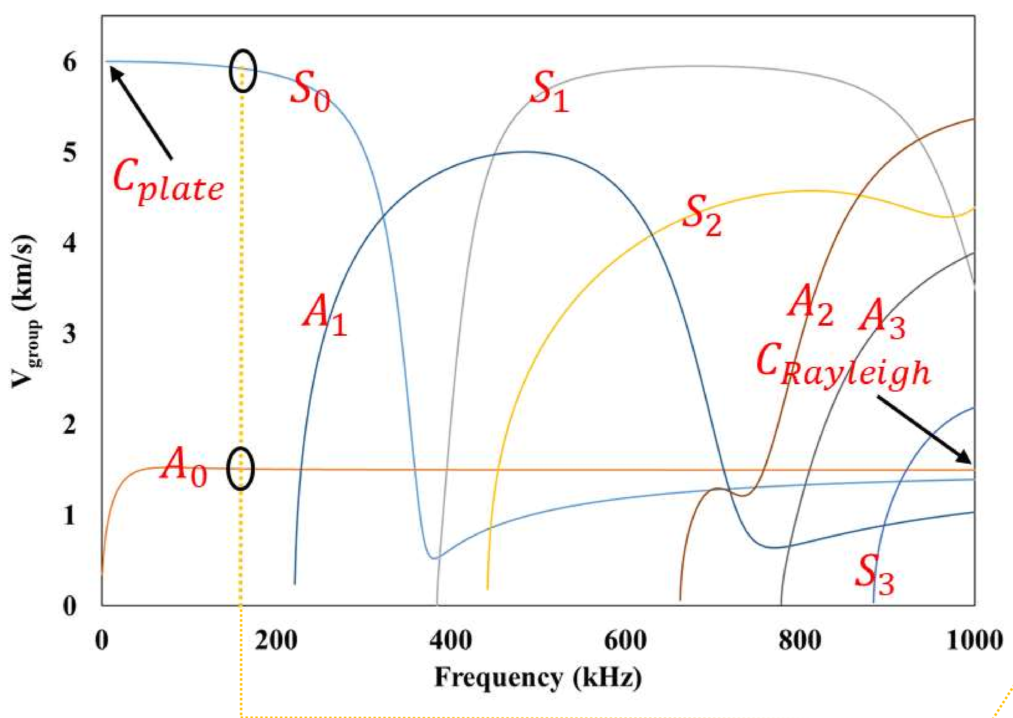
Here, $C_{66} = \frac{C_{11}-C_{12}}{2}$

Quasi-isotropic composite only have five independent stiffness coefficients.

$$\begin{cases} C_{11} = \dfrac{1-\nu_{23}\nu_{32}}{E_2E_3\Delta} \\ C_{12} = \dfrac{\nu_{21}+\nu_{31}\nu_{23}}{E_2E_3\Delta} \\ C_{13} = \dfrac{\nu_{31}+\nu_{21}\nu_{32}}{E_2E_3\Delta} \\ C_{33} = \dfrac{1-\nu_{12}\nu_{21}}{E_1E_2\Delta} \\ C_{44} = G_{23}, C_{66} = G_{12} \end{cases}$$

Here, $\Delta = \frac{1-\nu_{12}\nu_{21}-\nu_{23}\nu_{32}-\nu_{13}\nu_{31}-2\nu_{21}\nu_{32}\nu_{13}}{E_1E_2E_3}$

Dispersion of Group Velocity



Determination of three coefficients

① The stiffness coefficients in thickness direction C_{33} has little effect on the velocities of Lamb waves. ▶ C_{33} keeps constant.

② ν_{12} is approximately invariant. ▶ C_{12} is degraded at the same rate as that of C_{11}.

③ Out-of-plane Poisson's ratio is close to 0: $\nu_{31}, \nu_{32} = 0$ ▶ $C_{13} \approx 0$.

Determination of C_{11} and C_{44}

① $C_{plate} = \sqrt{\frac{C_{11}C_{33}-(C_{13})^2}{\rho C_{33}}}$ C_{13} is comparatively small ▶ $C_{plate} \approx \sqrt{\frac{C_{11}}{\rho}}$

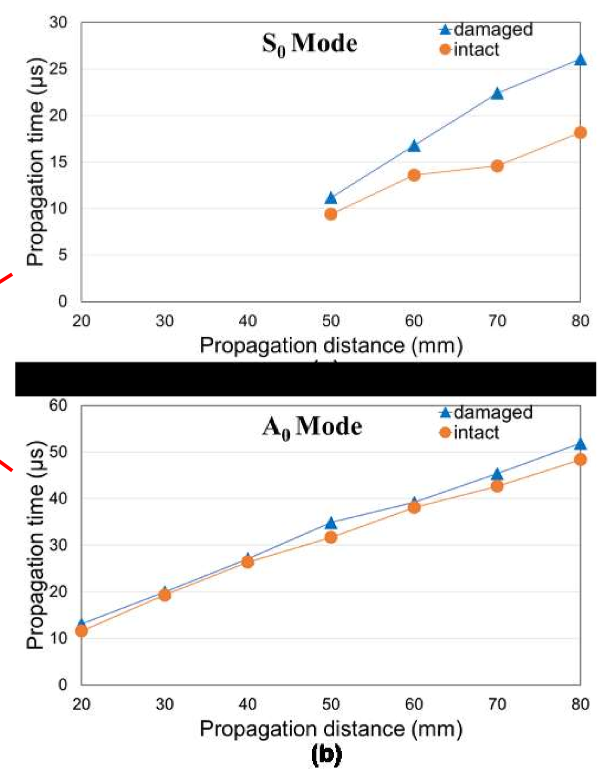
② $C_{Rayleigh} = \alpha C_{transverse} = \alpha\sqrt{\frac{C_{44}}{\rho}}$ α is close to 1 ▶ $C_{Rayleigh} \approx \sqrt{\frac{C_{44}}{\rho}}$

③ $C_{plate} \approx v_{S_0}$, $C_{Rayleigh} \approx v_{A_0}$

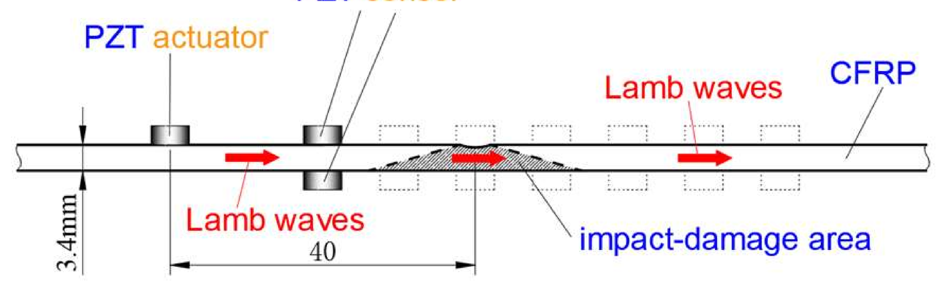
$\sqrt{\frac{C_{11}}{\rho}} \approx v_{S_0}$

$\sqrt{\frac{C_{44}}{\rho}} \approx v_{A_0}$

Velocity measurement of Lamb waves

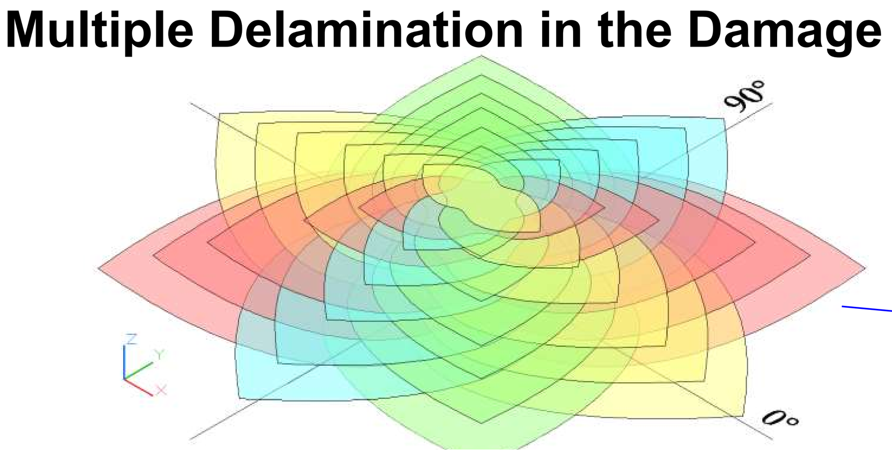


Experiment setup :

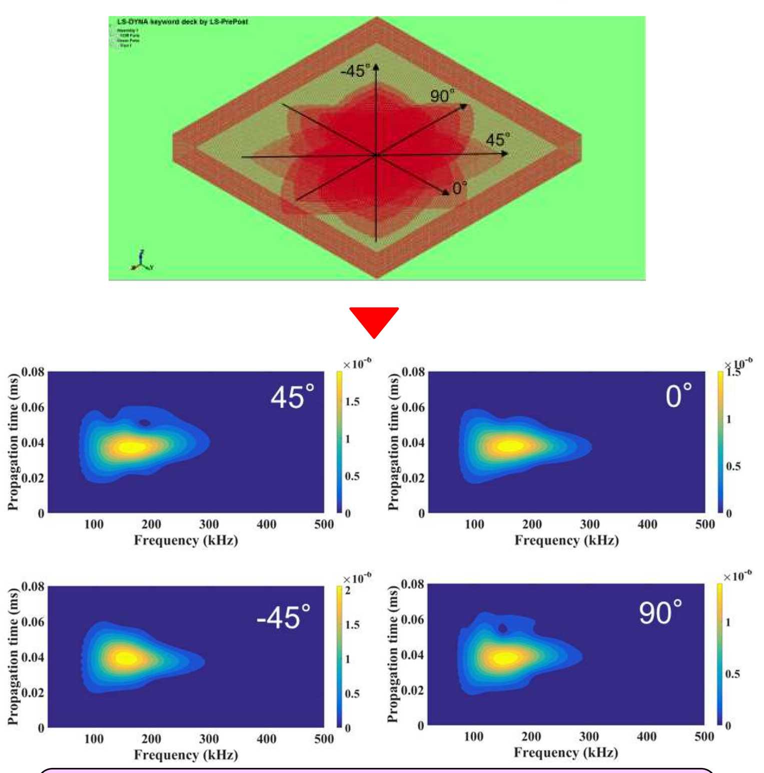


Simulation of Impact Damage

Multiple Delamination in the Damage

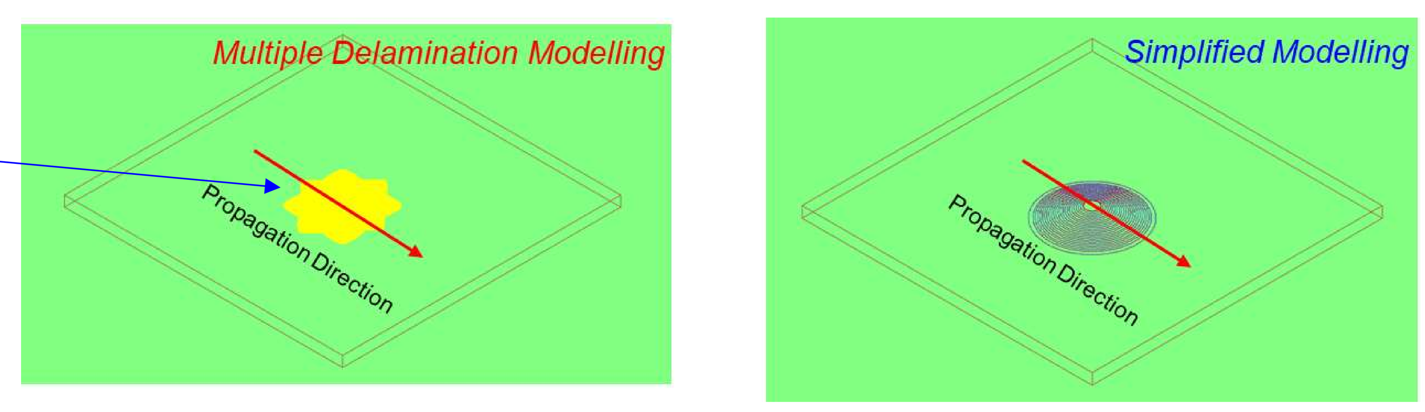


Experimental Confirmation of Quasi-isotropy

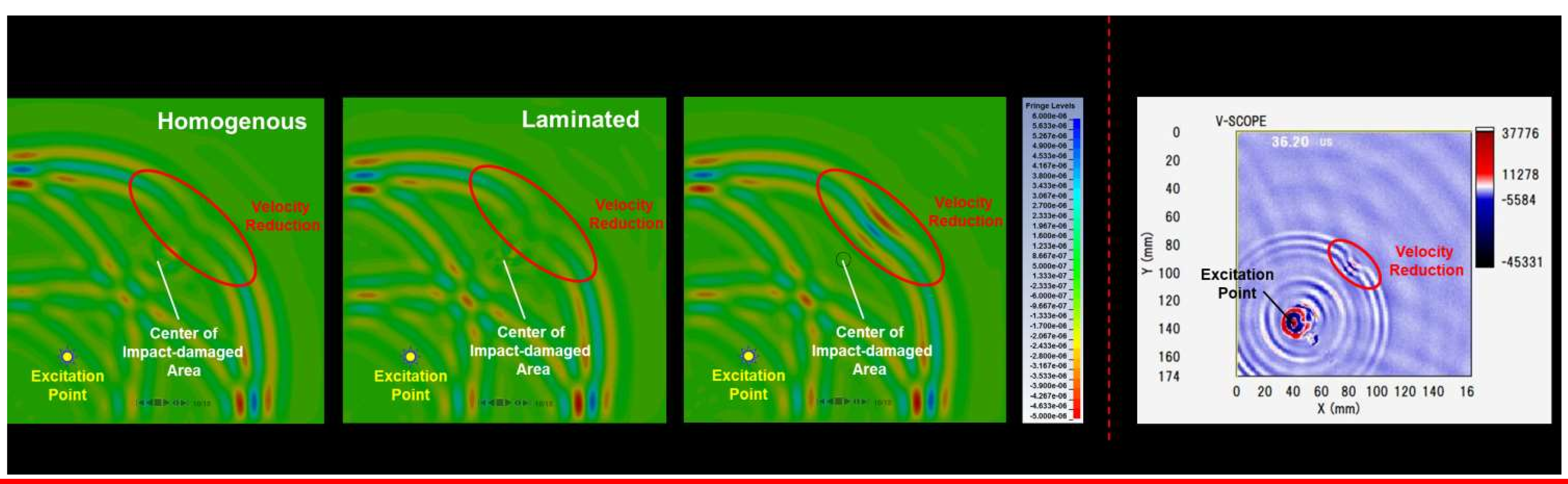


Propagation time and waveform are almost the same in different propagation directions.

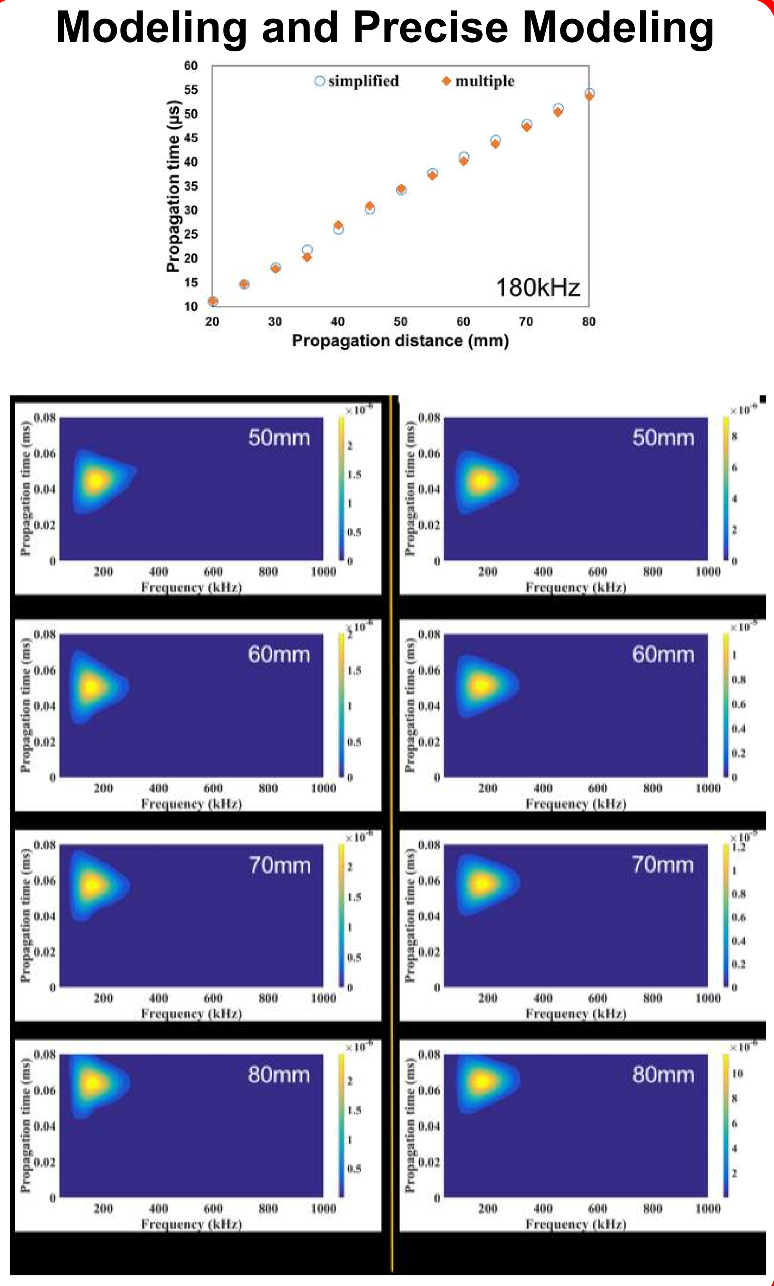
Verification of Simplified Modeling Method



Comparison of Wave Propagation Behavior



Comparison between Simplified Modeling and Precise Modeling



The agreement between simulation results and experimental observation results indicates the simplified modelling method is appropriate for simulating Lamb wave propagation behavior through impact damages in quasi-isotropic composite structures.