Geometric Effects on Ultrasonic Pulse Velocity

Measurements in Concrete Specimens

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Canada's NDT Conference
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Agenda

1. Introduction
2. Experimental Setups and Methodology
3. Results
4. Conclusions

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1. **Introduction**
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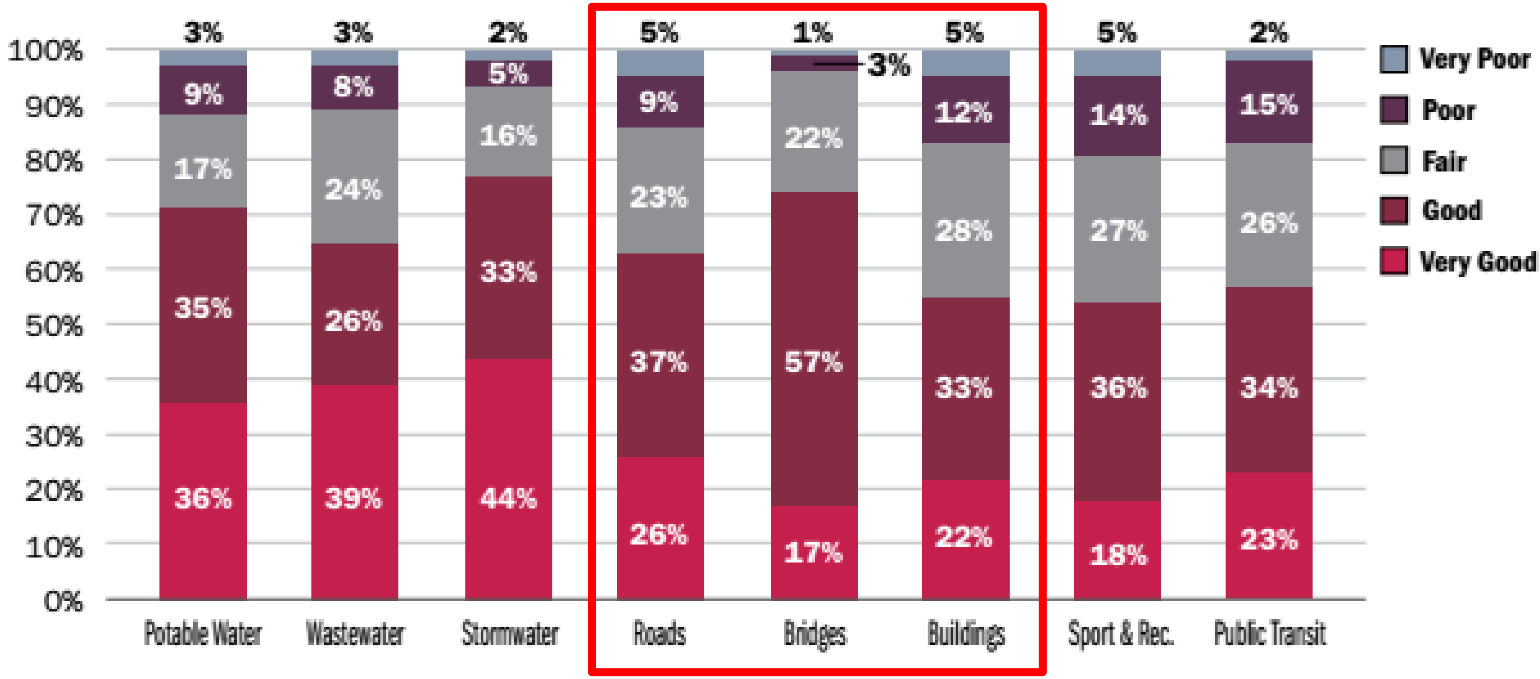
Introduction - WHY NDT

The Canadian Infrastructure Report Card (2016)



Summary of Average Physical Condition Rating

Introduction - WHY NDT

Infrastructure	Extrapolated Replacement Value of All Assets	Assets in Very Poor and Poor Condition	Assets in Fair Physical Condition	Anticipated Condition Based on Reported Reinvestment Levels (Improving, Stable, Declining)
		Replacement Value	Replacement Value	
Potable Water	$207 billion	$25 billion (12%)	$35 billion (17%)	Declining
Wastewater	$234 billion	$26 billion (11%)	$56 billion (24%)	Declining
Stormwater	$134 billion	$10 billion (7%)	$21 billion (16%)	Declining
Roads	$330 billion	$48 billion (15%)	$75 billion (23%)	Declining
Bridges	$50 billion	$2 billion (4%)	$11 billion (22%)	Declining
Buildings	$70 billion	$12 billion (17%)	$20 billion (28%)	Declining
Sport and Recreation Facilities	$51 billion	$9 billion (18%)	$14 billion (27%)	Declining
Transit	$57 billion	$9 billion (16%)	$15 billion (27%)	Unavailable
Total	**$1.1 trillion**	**$141 billion (12%)**	**$247 billion (22%)**	
Replacement Value per Household	**$80,000**	**$10,000**	**$18,000**	

The physical condition of the infrastructure (replacement value, extrapolated to the entire country)

Research objective

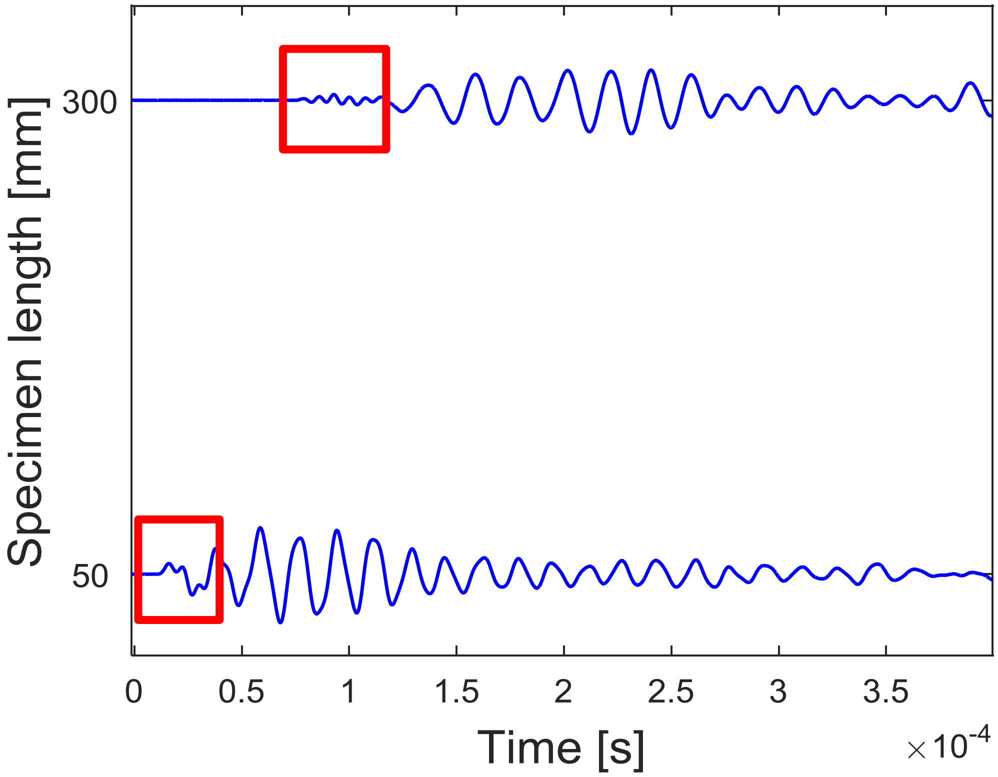
Effects of geometry on UPV results:

- Long specimen:

$$Vp = \underline{3712}\,\frac{m}{s}$$

- Short specimen:

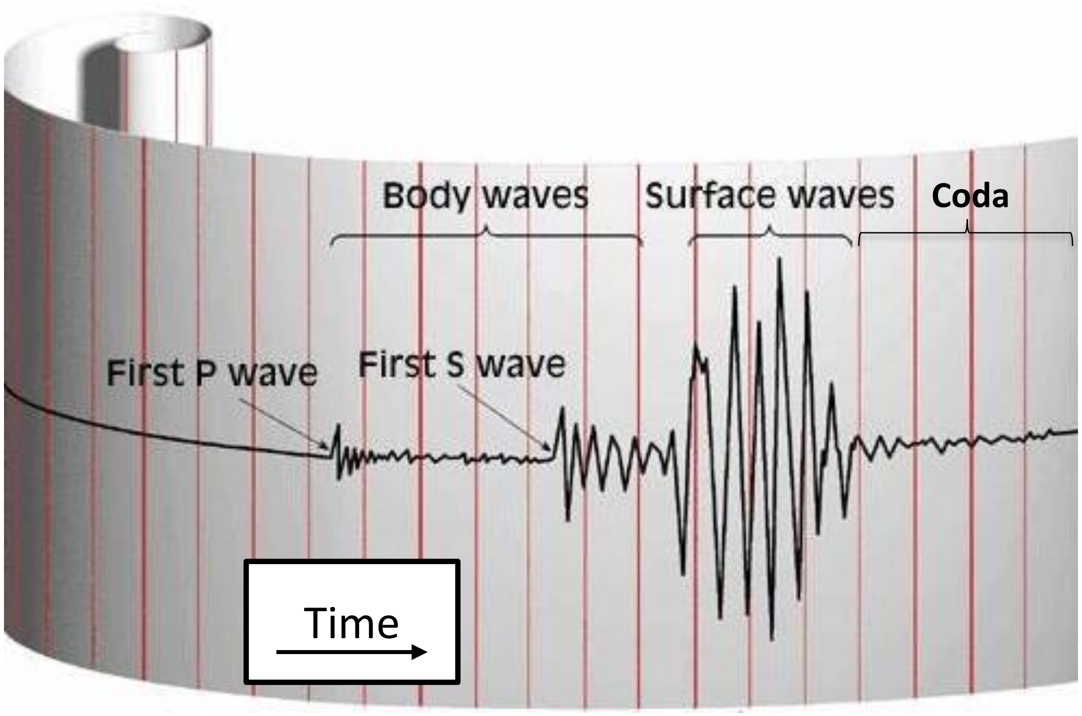
$$Vp = \underline{3840}\,\frac{m}{s}$$



How will the problem be addressed?

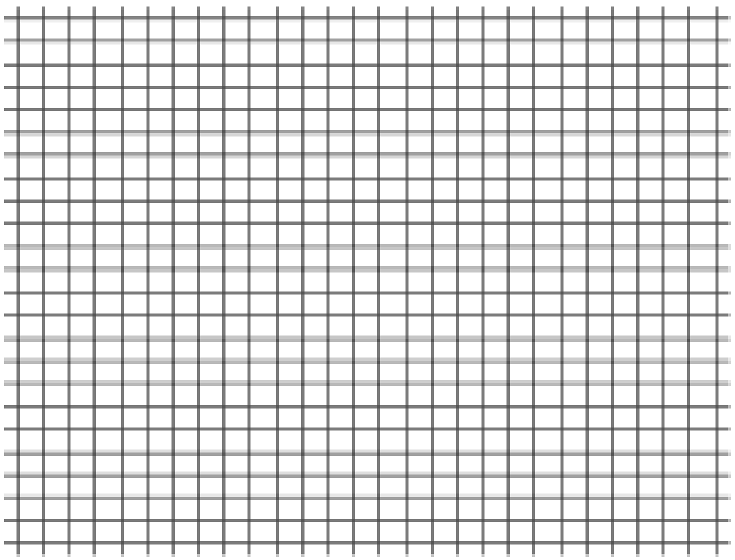
- Specimens with different dimensions
  - Lengths
  - Diameters
- Low (54 kHz) and high (850 kHz) transducers
  - Different wavelength
- Laser vibrometer

Ultrasonic A-Scan



http://www.sms-tsunami-warning.com/

Background: P-wave



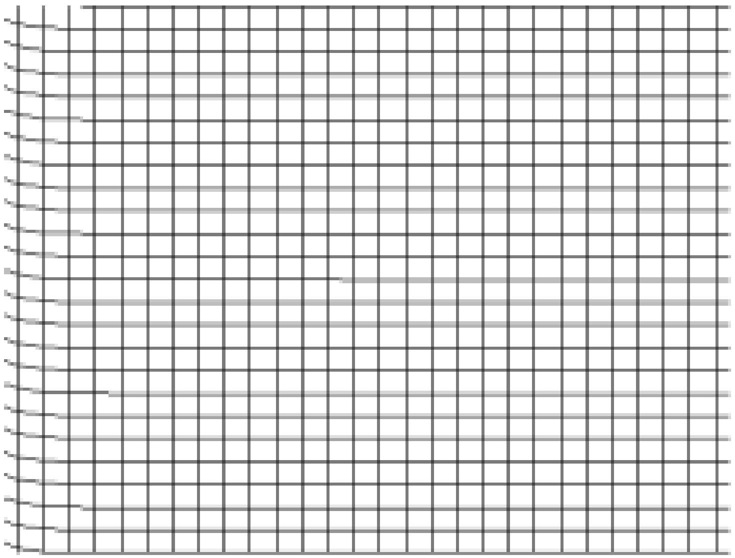
https://en.wikipedia.org/

$$V_P = \sqrt{\frac{M}{\rho}} = \sqrt{\frac{E_{\mathrm{d}}(1-v)}{\rho(1+v)(1-2v)}}$$

- Concrete:

typical range: 3000 - 4500 $\frac{m}{s}$

Background: s-wave



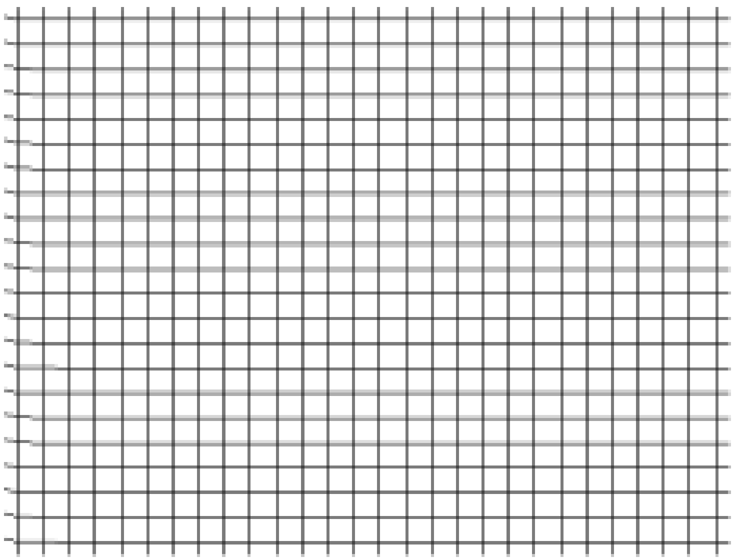
https://en.wikipedia.org/

$$V_S = \sqrt{\frac{\mu_L}{\rho}} = \sqrt{\frac{E_d}{2\rho(1+v)}}$$

- Concrete:

typical range: 2200 - 2700 $\frac{m}{s}$

P and s-waves separation



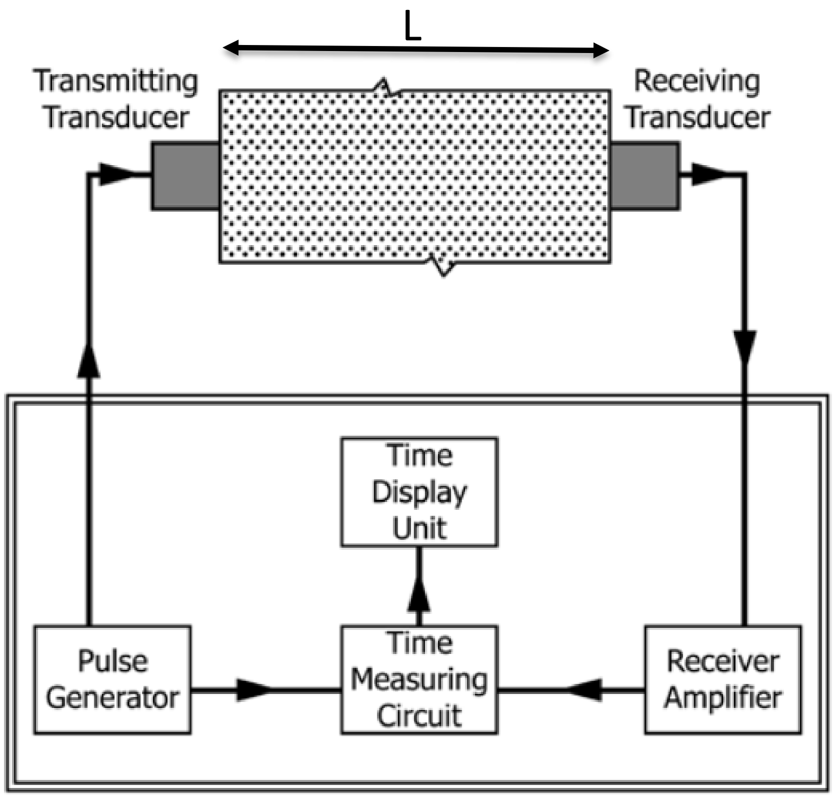
https://en.wikipedia.org/

- The separation between P and S-waves is possible as the distance increases

Background: Ultrasonic Pulse Velocity

- Ultrasonic Pulse Velocity (UPV) method is a popular simple NDT technique used in Civil Engineering.
- UPV is an ASTM standard test method for concrete specimens
- Time of a first arrival of ultrasonic wave from one side of the specimen to another.
- Results depend on the transducers used, the coupling quality, and the specimen dimensions.

Background: UPV



ASTM: C597 - 16

$$V_P = \frac{L}{t}$$

L – distance between transducers
t – time of flight

Recommended transducers with f_c = 20 to 100 kHz

Background: Ultrasonic Pulse Velocity (UPV)

UPV is used to:

- assess the uniformity and relative quality of concrete,
- indicate the presence of voids and cracks,
- evaluate the effectiveness of crack repair,
- indicate changes in the properties of concrete,
- estimate the severity of deterioration or cracking.

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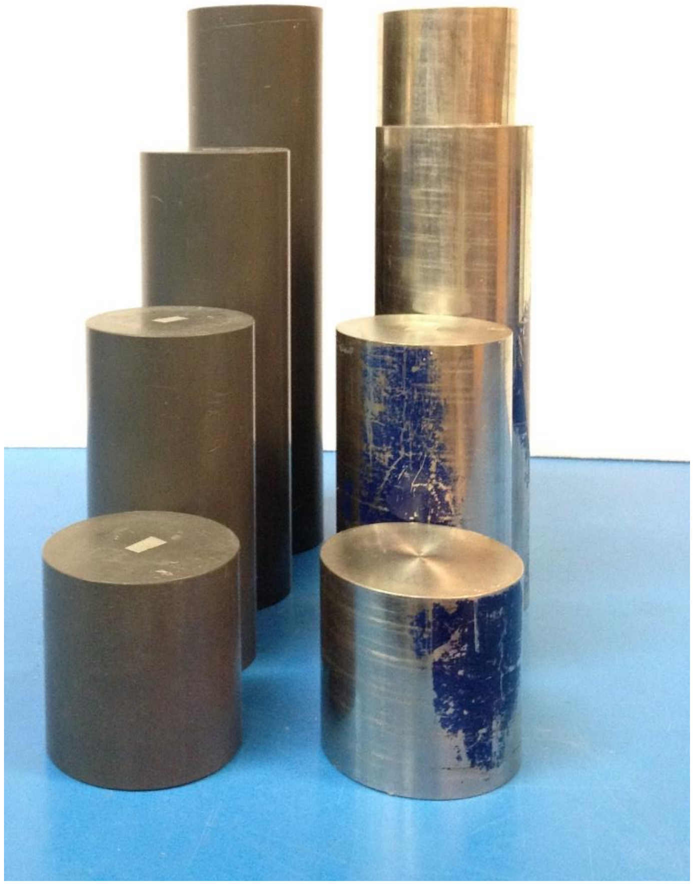
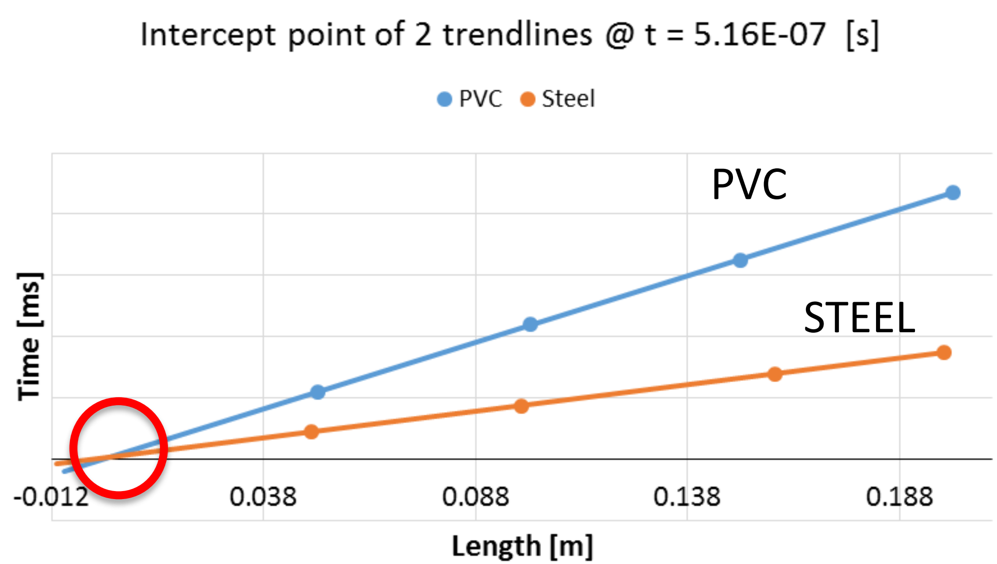
Calibration – system delay



Calibration on 8 rods made from PVC and Steel



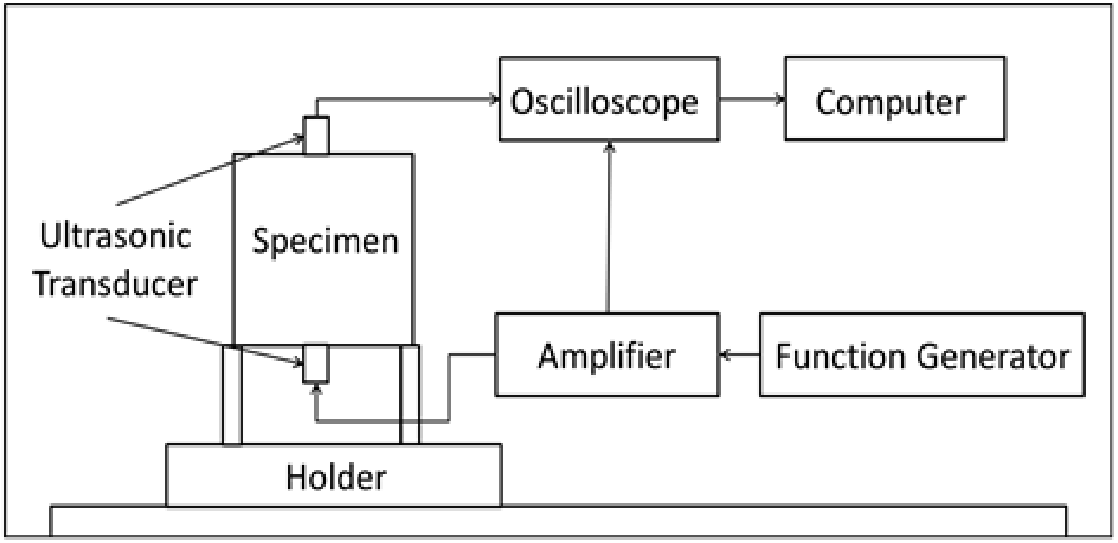
Specimen and sensor effect on UPV tests

- Ultrasonic transmitter / receiver
- Ultrasonic transmitter / laser

- 9 concrete specimens

Experimental Setups: first arrival measurements

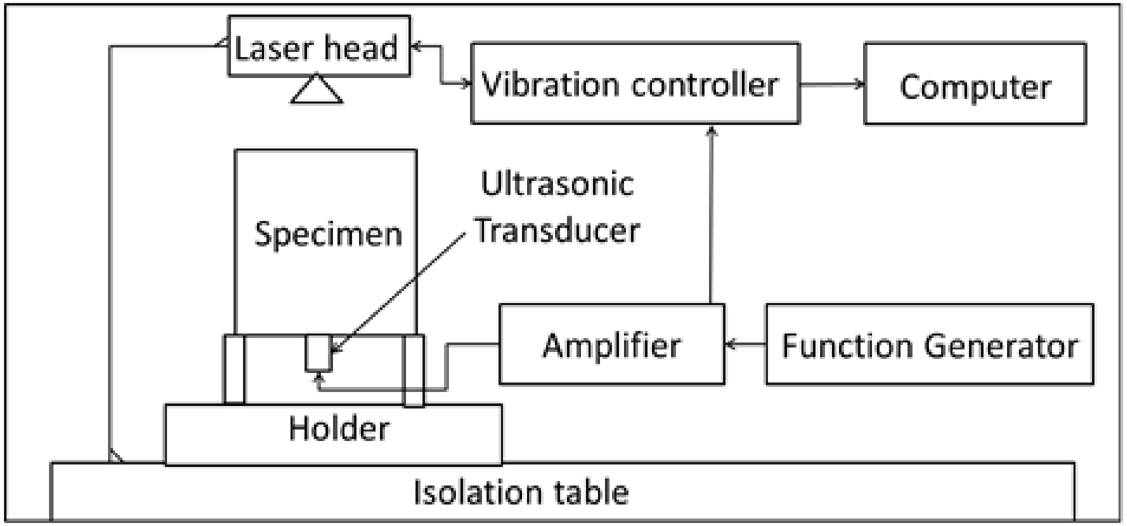
- Ultrasonic **transmitter / receiver**



Type of transducer (v_p =3760 m/s)	Wavelength [mm]
Low frequency (fc = 54 kHz)	74.97
High frequency (fc =850 kHz)	3.76

Experimental Setups: first arrival measurements

- Ultrasonic **transmitter / laser vibrometer**



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SPECIMEN AND SENSOR EFFECT ON UPV TESTS

Configuration 1:

- Ultrasonic transmitter / receiver (T/R)

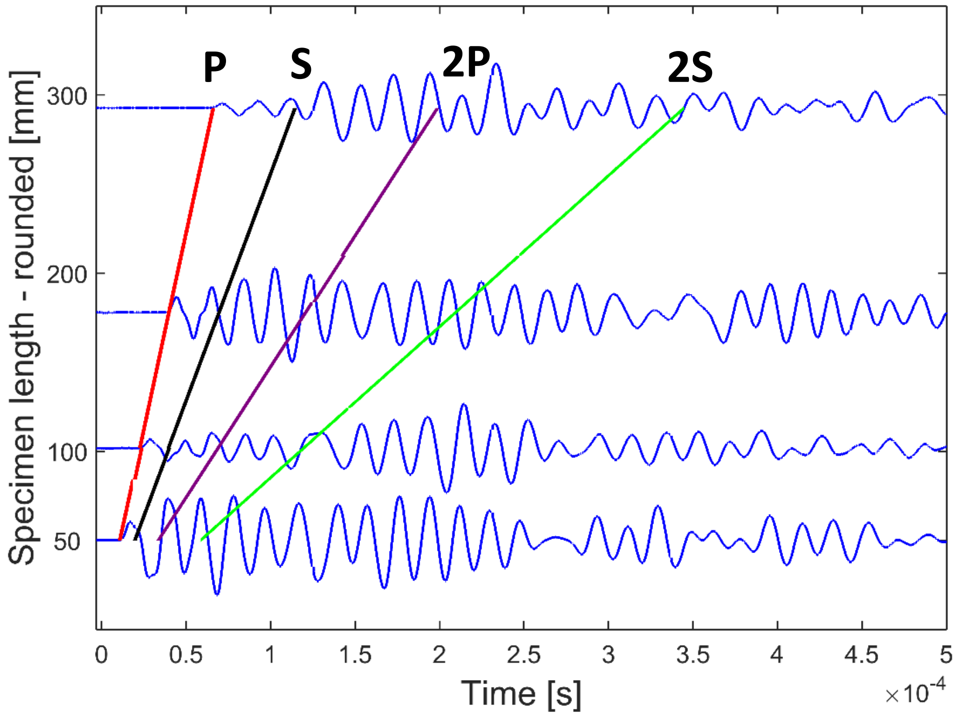
Configuration 2:

- Ultrasonic transmitter / Laser (T/L)

2 types of transducers: - 54 kHz,
- 850 kHz

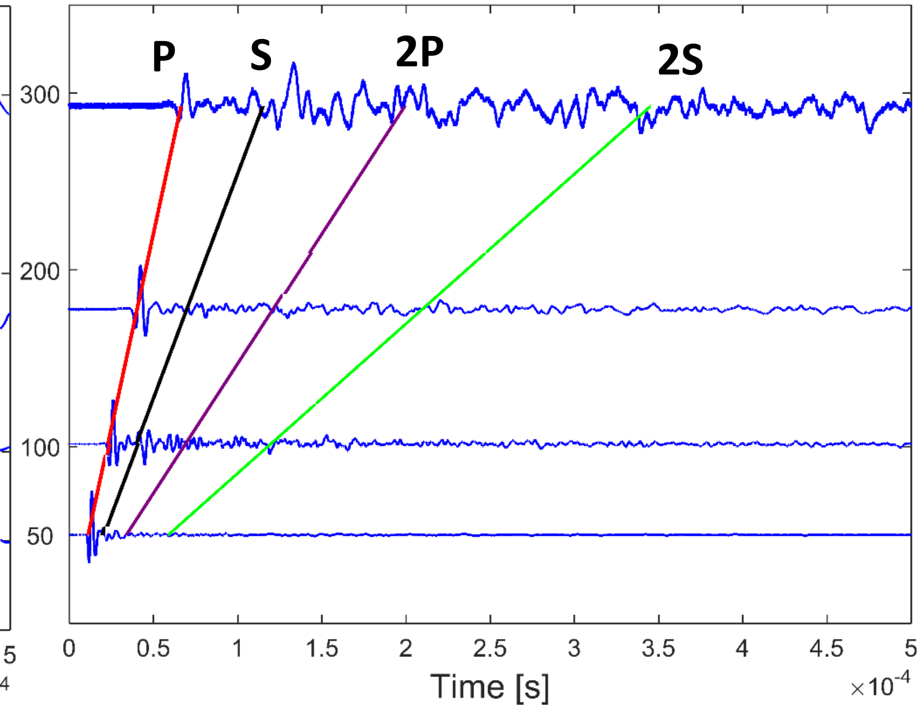
UPV results: Sample time traces (T/R)

54 kHz



- S-wave is dominating

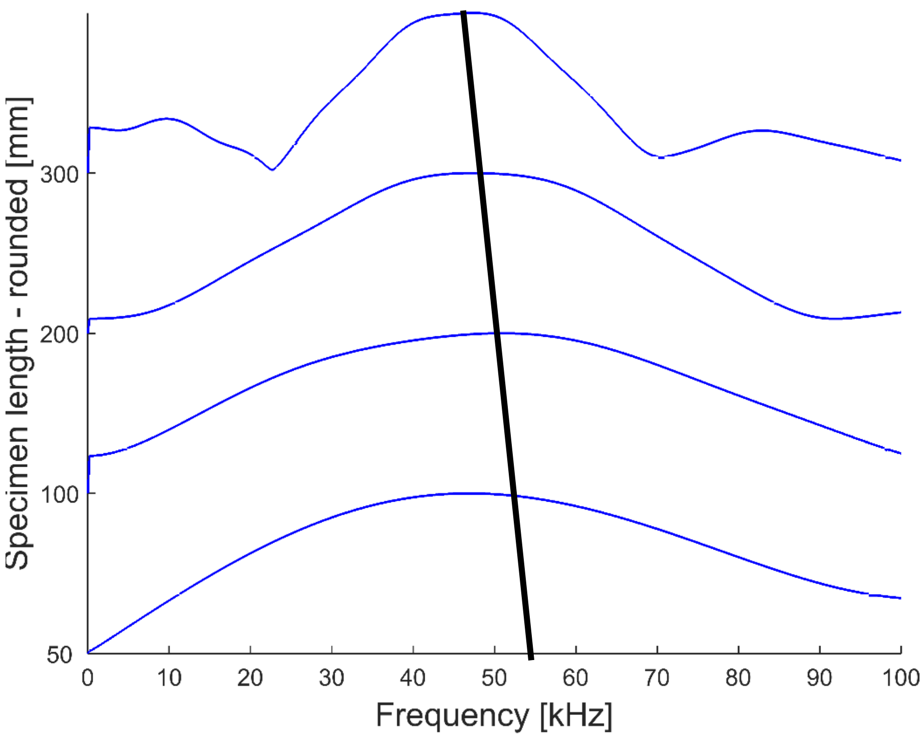
850 kHz



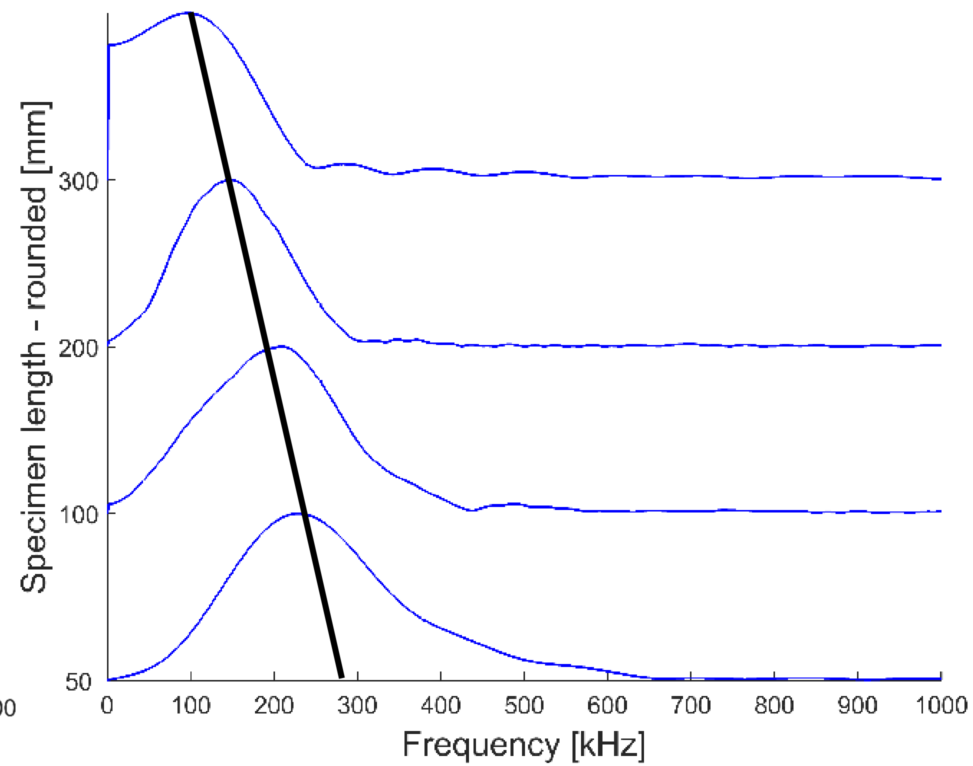
- P-wave is dominating

UPV results: Length effects (T/R)

54 kHz – P and S

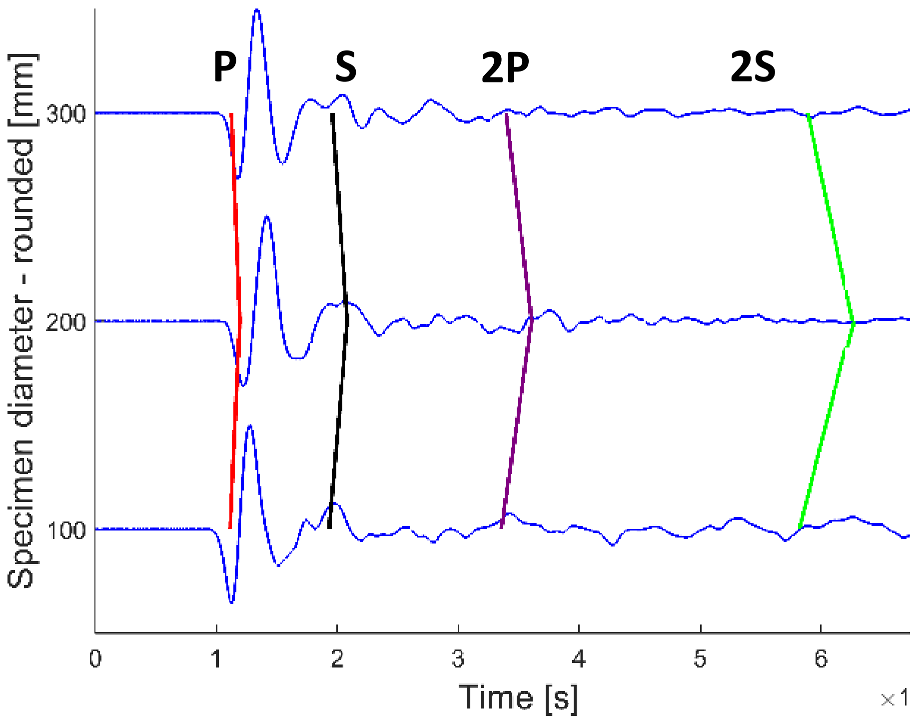


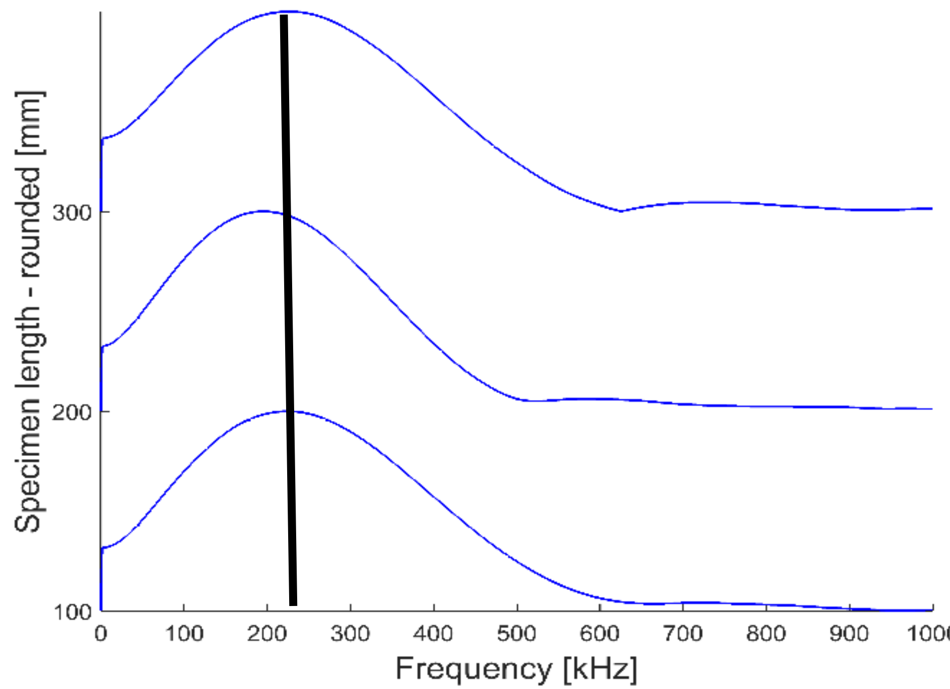
850 kHz - P



UPV results: Diameter effects (T/R)

850 kHz





- Low influence on UPV results

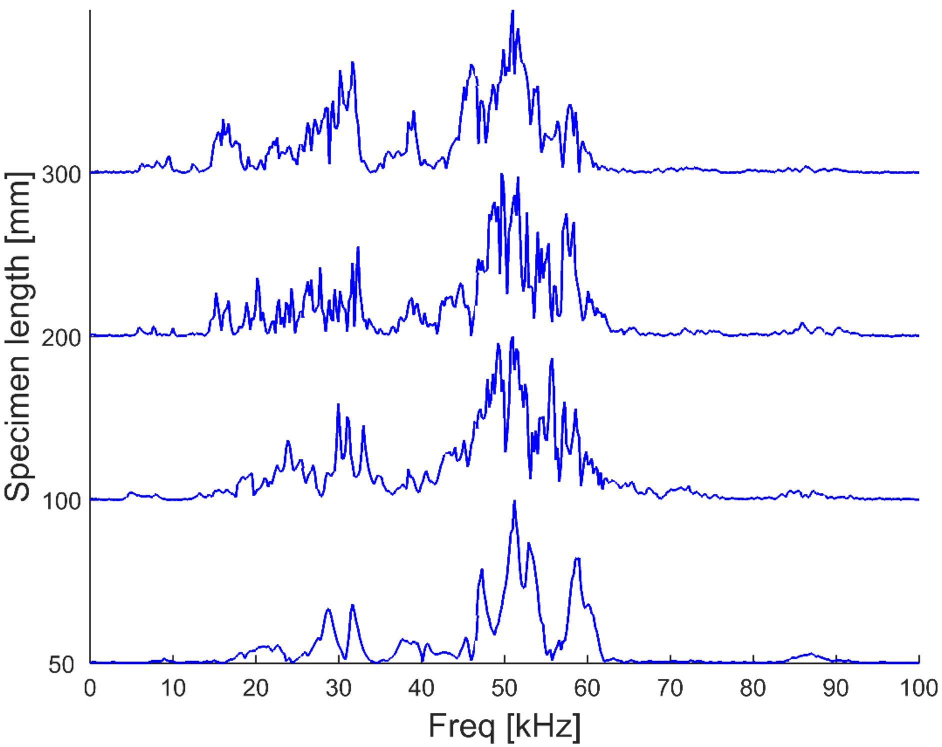
Why laser vibrometer?

- Measurements at a selected location
- No mass is added to the system
- Signals recorded with laser have physically interpretable units

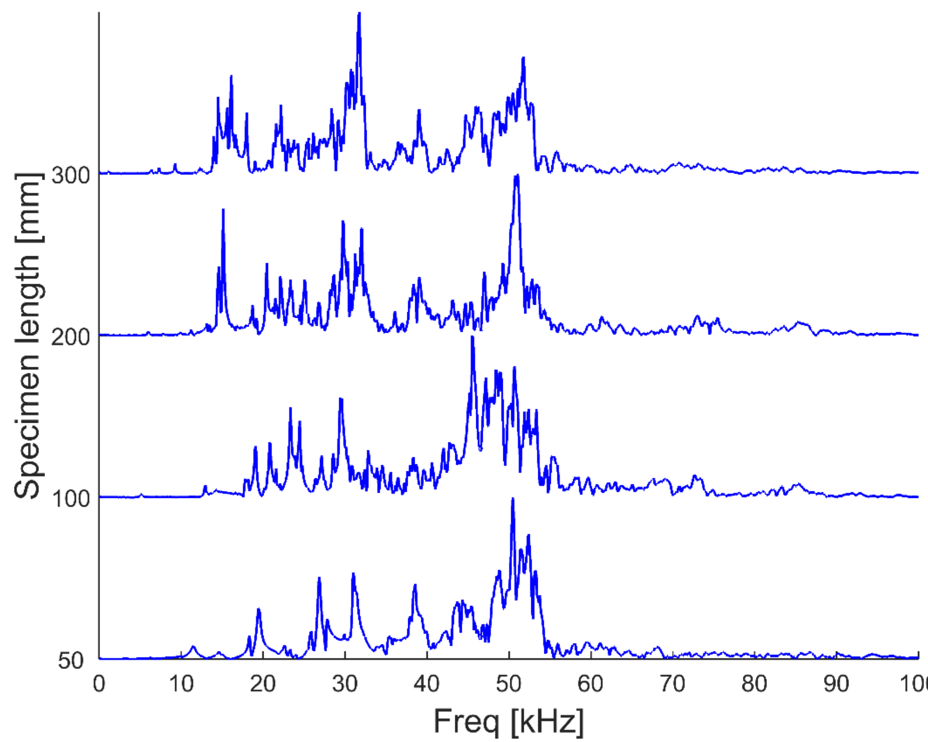
Why laser vibrometer?

- response is free from frequency components coming from the receiver

Transducer

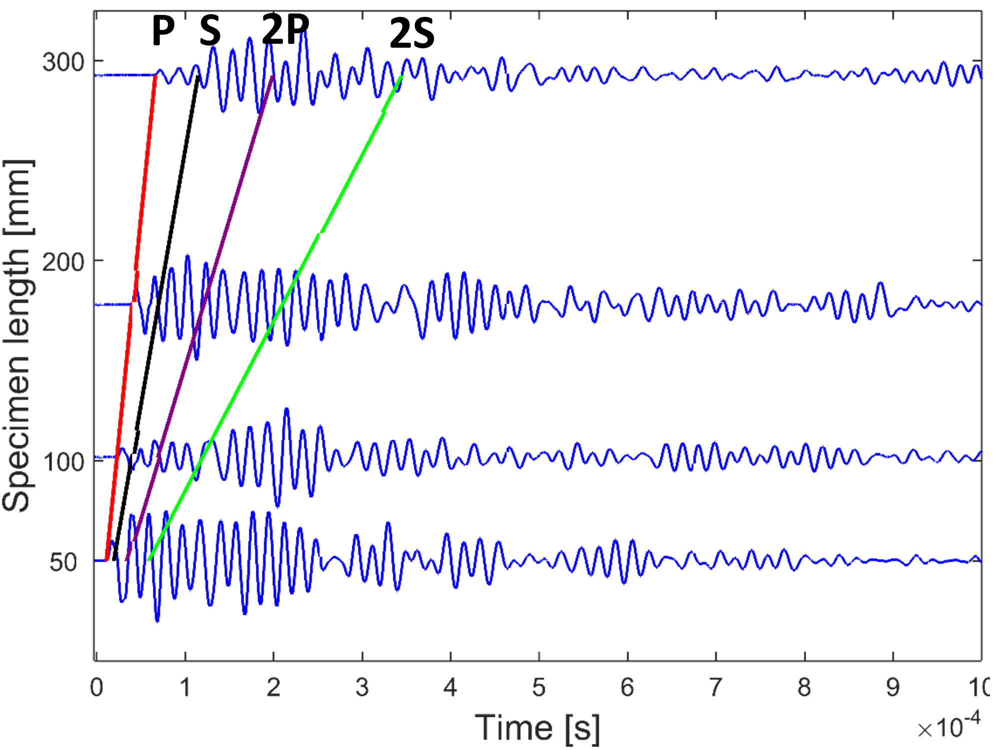


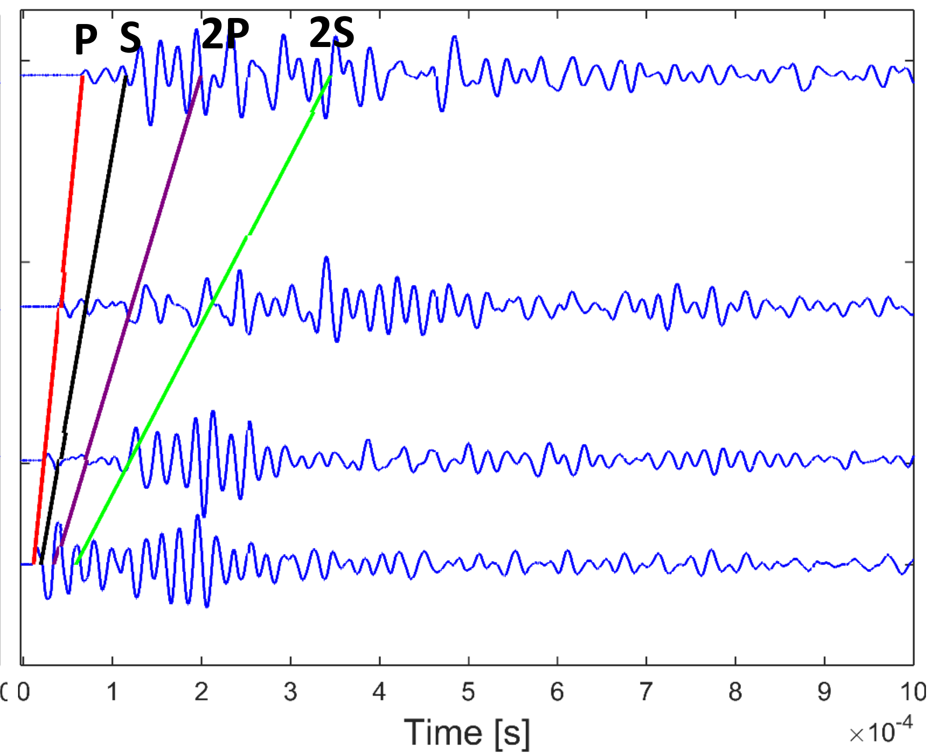
Laser



UPV results – 54 kHz

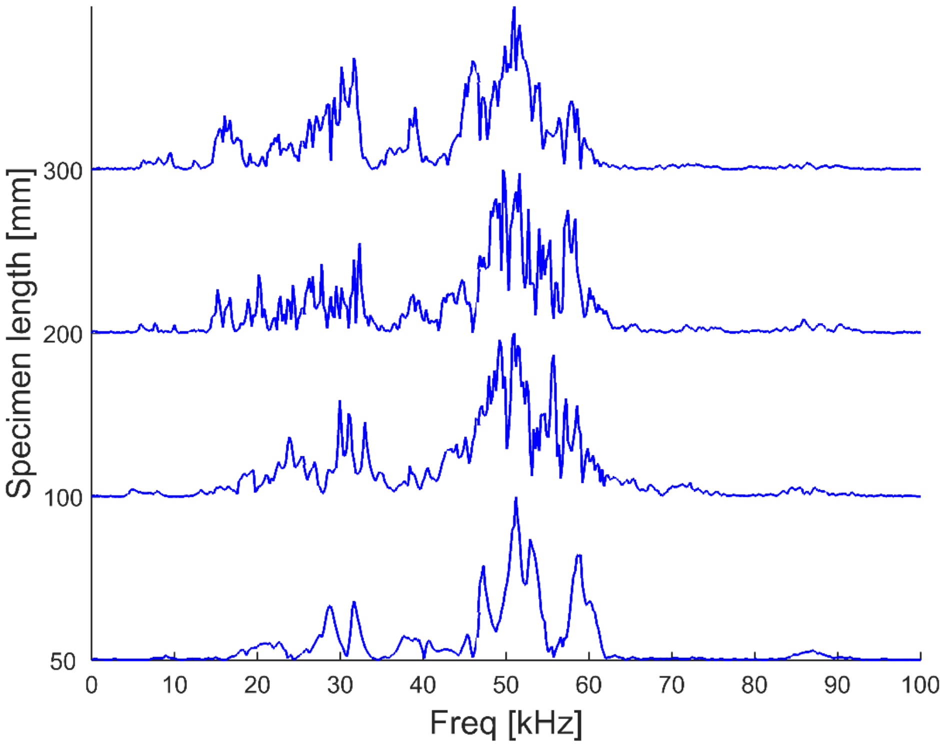
- Transmitter
- Laser



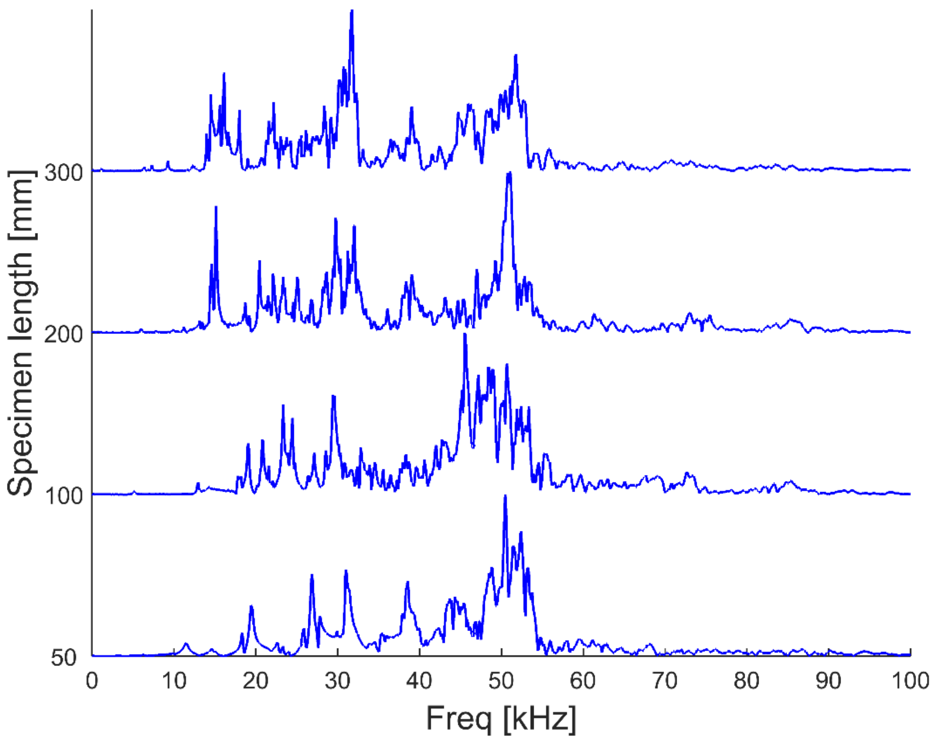


UPV results – 54 kHz

- Transmitter

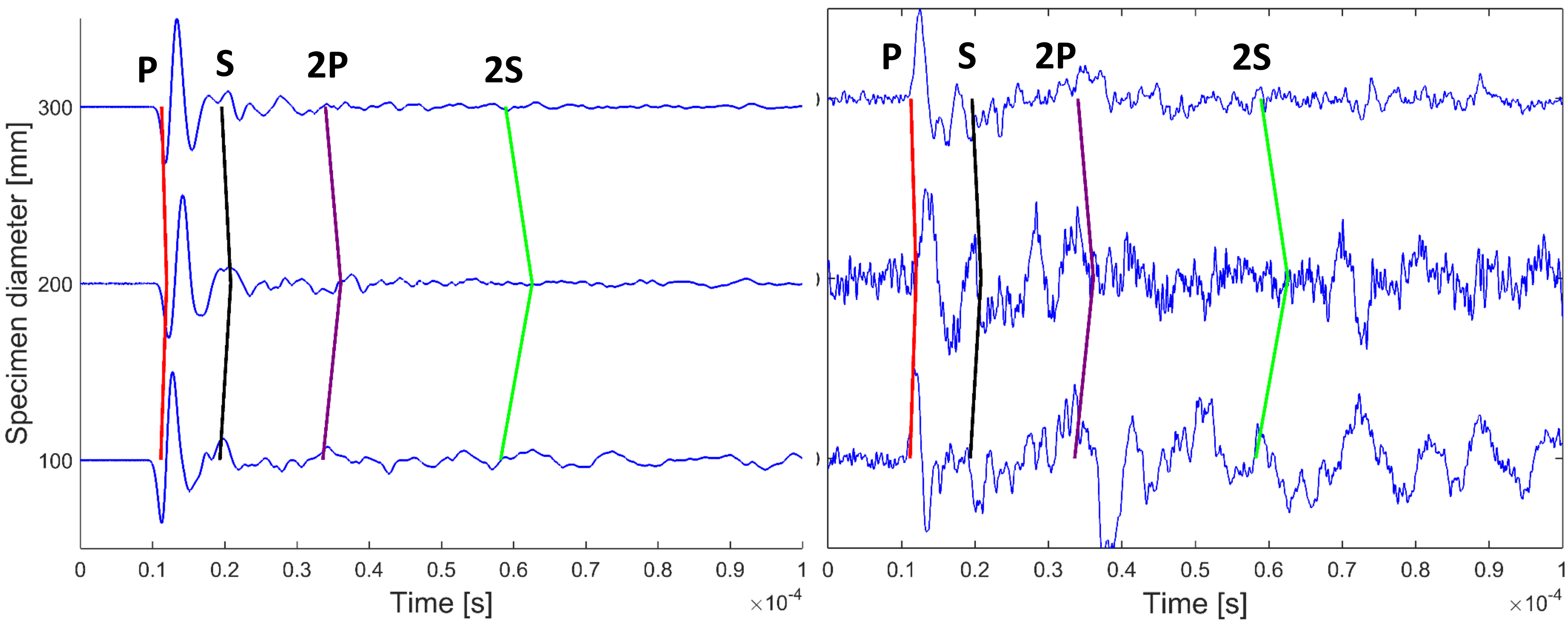


- Laser



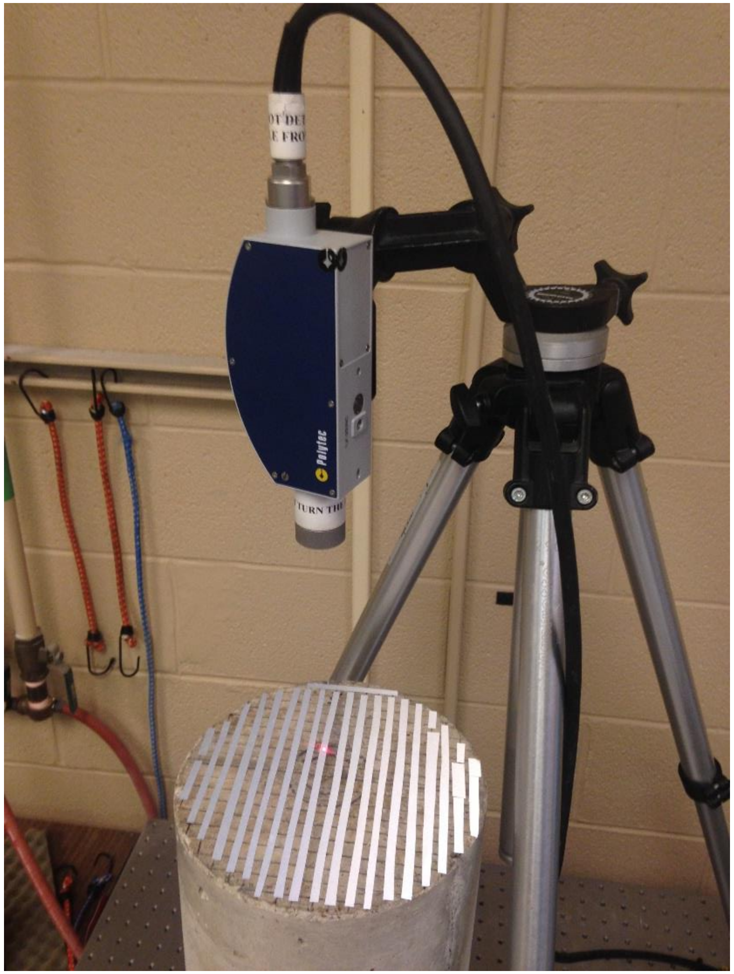
UPV results – 850 kHz

- Transmitter
- Laser



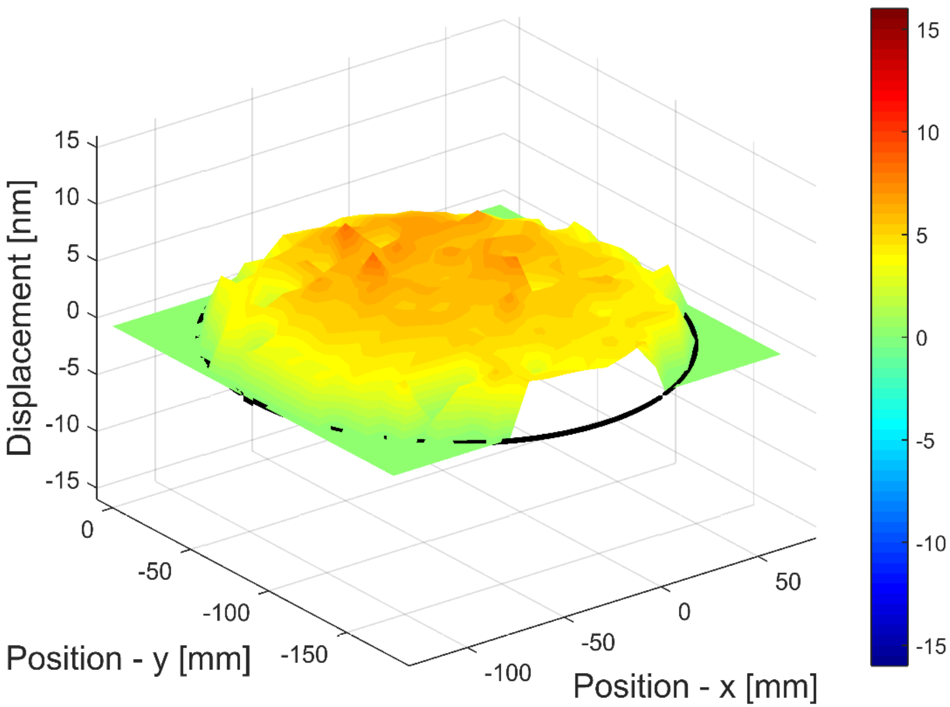
UPV results - 54 kHz
Laser surface scanning

- 19 measuring lines
- 289 points



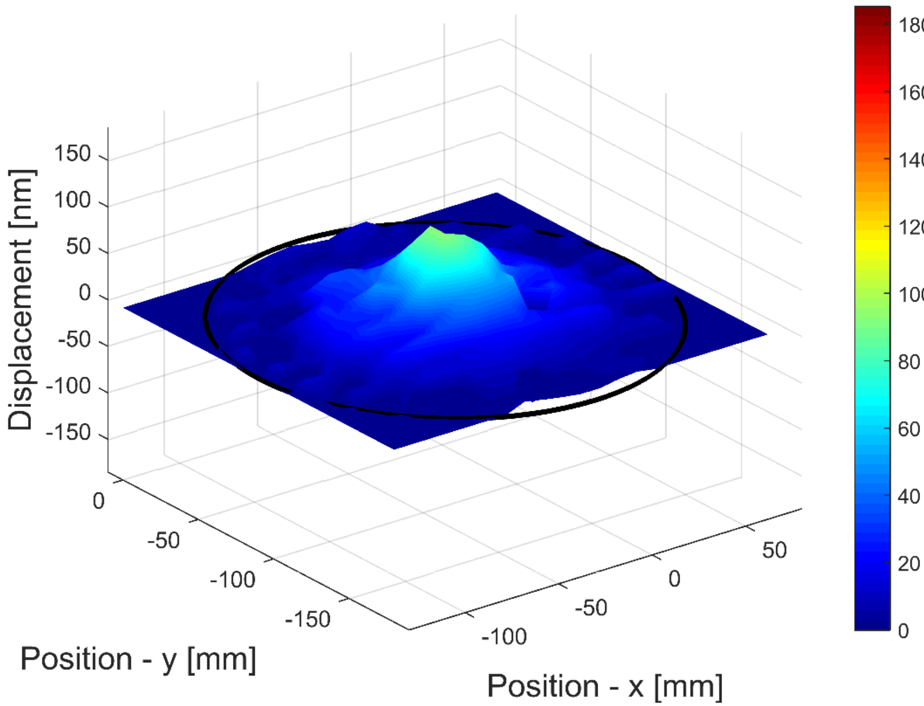
UPV results – Laser scanning

- P-wave



Plane character
small amplitude

- Main Energy



Guided character
high amplitude

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Conclusions

- f_c = 20 to 100 kHz => long wavelength
- For short specimens P and S arrivals might be mistaken
- P and S waves separation impossible for short specimens (less than 3λ)
- Length of test specimen should exceed more than one wavelength recommended by ASTM

Conclusions

- High frequencies imply higher attenuation (however smaller specimens can be used)
- Signal character depend on transducers used in the tests
- Increasing diameter of the specimen has minor influence on UPV results
- P-wave arrives with a plane character, while main energy travels with a guided character

Thank you!