# ATTEMPT TO MEASURE VELOCITY AT LOW FREQUENCY BY MODIFIED TRI-AXIAL DESTRUCTIVE INSTRUMENT

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## ABSTRACT
Velocity data measured at frequencies of several hundreds of kHz to a few MHz by ultrasonic transducers using core plugs in laboratories are different from velocities obtained in fields. The velocities obtained in the laboratories are not appropriate to delineate reservoir characteristics. In this study, low-frequency measurements are carried out at low cost by modifying an existing instrument, which is a tri-axial destructive instrument. The reliability of the modified instrument is confirmed by monitoring the waveform of a low-frequency vibrator. Young's moduli of an aluminum sample are measured using strain gauges with an order of $10^{-6}$ accuracy. Young's moduli are measured using frequencies ranging from 20 to 160 Hz using a low-frequency vibrator, and travel time are measured at 500 kHz using an ultrasonic transducer. The measurements are conducted under various overburden pressures. The elastic moduli (the bulk moduli, shear modili, Vp, and Vs) for the various frequencies and pressures are calculated from measured Young's moduli. The elastic moduli at low frequencies obtained from measurements. We confirmed that we are able to obtain Young's modulus in the laboratory using our modified existing instrument.

## INTRODUCTION
In general, velocities obtained in laboratory measurements and field measurements are different. Elastic velocities of core samples are measured at high frequencies in the laboratory and actually measured travel time, whereas well logging and seismic surveys at fields are conducted using low frequency vibrations. This phenomenon is called frequency dispersion. Measurement of elastic velocities at low frequencies in laboratory to mimic the field survey conditions is one of the keys for up scaling the laboratory data to the field data.

In this study, we modified a tri-axial destructive instrument to carry out low-frequency measurements of the Young's moduli of aluminum. Velocities were calculated from abouve moduli, and measured travel time at high frequency for the same aluminum sample.

# METHODS

### Instrument preparation

In order to carry out the low-frequency measurements, we need to generate low frequency waves propagating through core samples. The direction of compressional wave propagation needs to be along the axis of core samples. In this study, we installed a low frequency vibrator to the axis pressure rod of the existing the tri-axial destructive instrument. This vibrator is operated by hydraulics. The schematic diagram of the measurement system is shown in Figure 1. The specifications of the vibration system are: stroke, 5mm; diameter of the cylinder, 100mm; diameter of the rod, 56 mm; frequency, 0 to 160 Hz; generating pressure, 0 to 3045 psi. The vibrator system is shown in Figure 2 and Figure 3.

### Sample preparation

A core sample of aluminum with 38 mm (1.5 inches) diameter and about 50 mm length was used. A photograph of the aluminum is shown in Figure 4. Gauges were glued to the edges (for vertical stress and strain measurements) and the sides (for lateral stress and strain measurements) of the core plug. The strain gauges were 5 mm in length, and the resistance of the gauge was 120.2±0.3Ω. The gauge factor was 2.12±1.0%, the adoptable thermal expansion was 11.7 PPM/ºC and the transverse sensitivity was 0.4%.

### Measurement procedure

The measurement procedures were as followings:

1) After the sample is set in the instrument, lateral and axis overburden pressures are applied up to 1000 psi; the overburden is applied by a load cell.
2) The vibrator is stared at a frequency of 20 Hz.
3) The vertical and lateral stress and strains of the core sample are measured at the axis pressures of vibration about 120 psi. These pressures are very strong in order to measure the elastic moduli in a dynamic condition. In this experiment, stress and strain are measured by strain gauges of $10^{-6}$ sensitivity. The strong pressures are necessary to obtain vivid waveforms of stress and strain.
4) The frequency of the vibration is increased by 20 Hz and the process 3) is repeated. The frequencies used in the measurement are every 20 Hz from 20 Hz to 160 Hz.
5) The overburden pressure is increased to 2000 psi, and the processes 3) and 4) are repeated. The overburden pressures used in the measurement are 1000, 2000 and 3000 psi.

The measurements of travel time are carried out at the high frequency, 500 kHz, at the same overburden pressures as used above.

The static bulk modulus (*K*) and shear modulus (G) are calculated from Young's modulus (*E*) and Poisson's ratio (ν) by using equations (1) and (2).

$$K = \frac{E}{3(1-2\nu)} \tag{1}$$

$$G = \frac{E}{2(1+\nu)} \tag{2}$$

Compressional velocity (Vp) and shear velocity (Vs) are calculated from equations (3) and (4).

$$Vp = \sqrt{\frac{K+4G/3}{\rho}} \tag{3}$$

$$Vs = \sqrt{\frac{G}{\rho}} \tag{4}$$

## RESULTS AND DISCUSSION

The strain values of the aluminum sample at 100 Hz are plotted in Figure 5. The period of a waveform is about $1.0075\times10^{-2}$ ms (from Figure 6) and we confirm that the aluminum sample is vibrated at about 100 Hz. Thus, the modified instrument works well to generate the low-frequency waves. A relationship between velocities and frequency of the aluminum sample at 1000, 2000 and 3000 psi overburden pressure of vibration is shown Figure 7. These velocity data are in agreement with literature values (Chronological Scientific Tables) as 6.42 km/sec for the P-wave and 3.04 km/sec for the S-wave. The average of measured velocities at low frequencies is 6.354 km/sec for the P-wave and 3.077 km/sec for the S-wave. The measurements at 500 kHz are 6.325 km/sec for the P-wave and 2.835 km/sec for the S-wave.

## CONCLUSION

An existing tri-axial destructive instrument was modified at low cost. The Young's moduli of aluminum were measured by vibration at low frequency. The frequencies of generated vibrations were confirmed by monitoring the waveform. The velocities were calculated from Young's moduli, and obtained velocities data are in agreement with the literature. In this experiment, frequency dispersion was not confirmed; however we confirmed that velocities are affected by overburden pressures.

In the future, we will carry out the same experiments using rock samples. Furthermore, we will improve the accuracy of our modified instrument and the strain gauge ($10^{-7}$ accuracy) in order to conduct detailed measurements to clarify the relationship between velocity and vibration pressure.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. National Astronomical Observatory of Japan. *Chronological Scientific Tables*, Maruzen Co., LTD, Tokyo, 2009, 422-423.

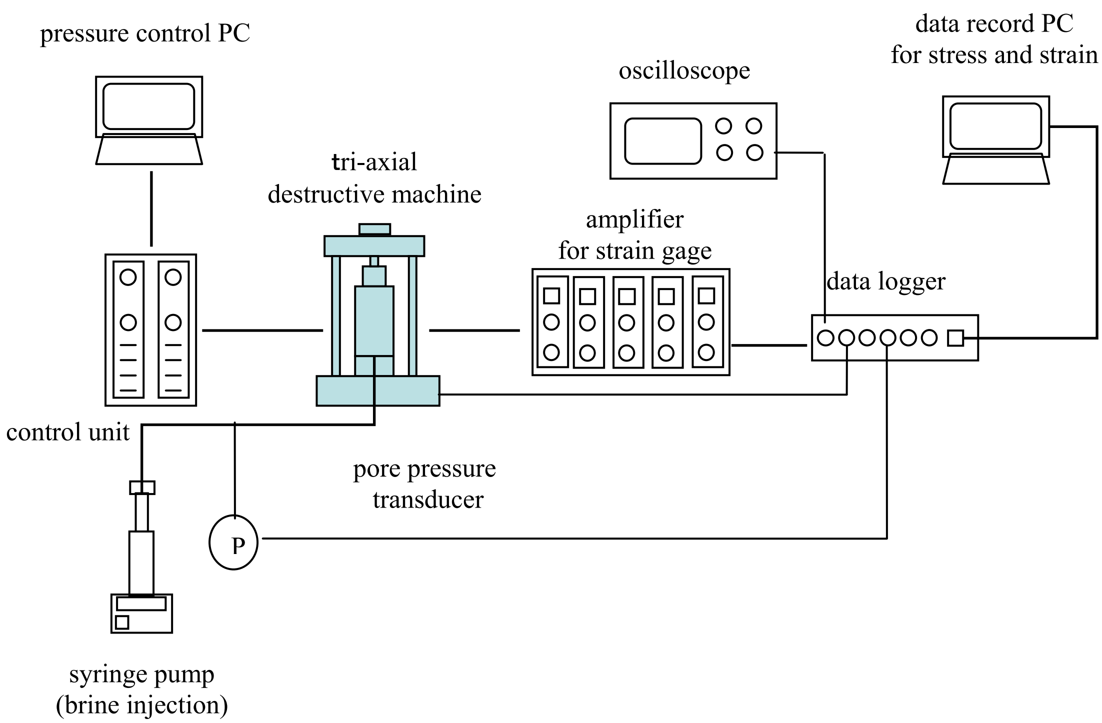


Figure 1.Diagram of pressure and data system

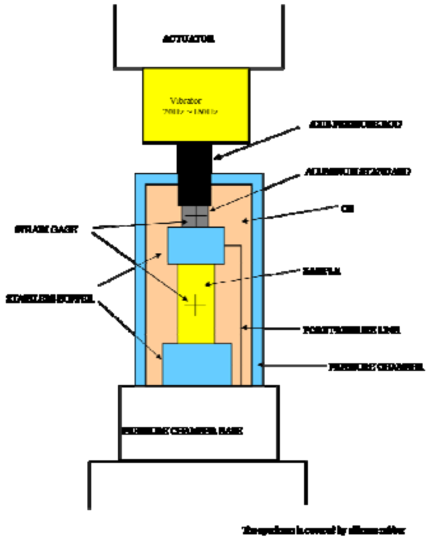


Figure 2. Description image of tri-axial destructive instrument. Vibrator is installed at axis rod. The ranges of vibration are 20Hz to 160Hz apply. Velocity is calculated from stress and strain by strain gauges.

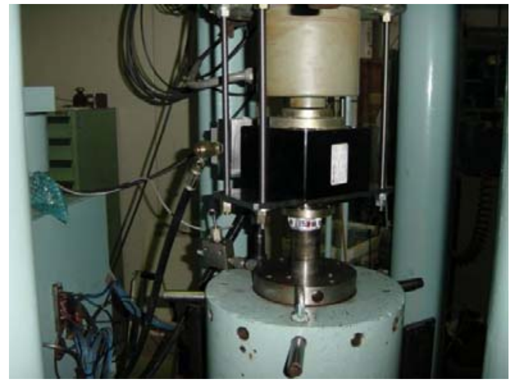

Figure 3. Vibrator (black box)

Figure 4. strain gauges are glued on the aluminum sample.

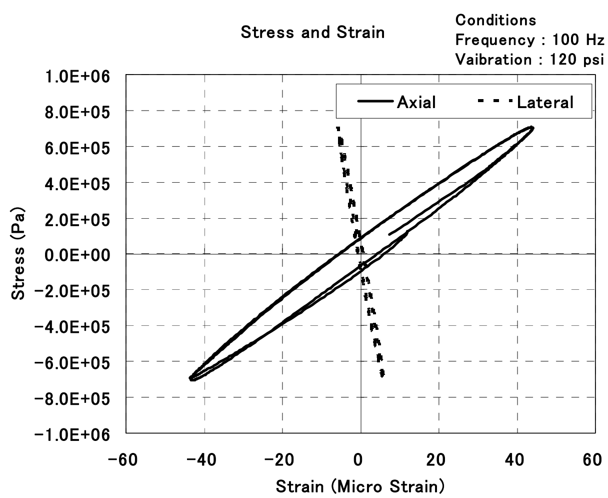


Figure 5. lissajou’s of stress and strain of the aluminum sample.

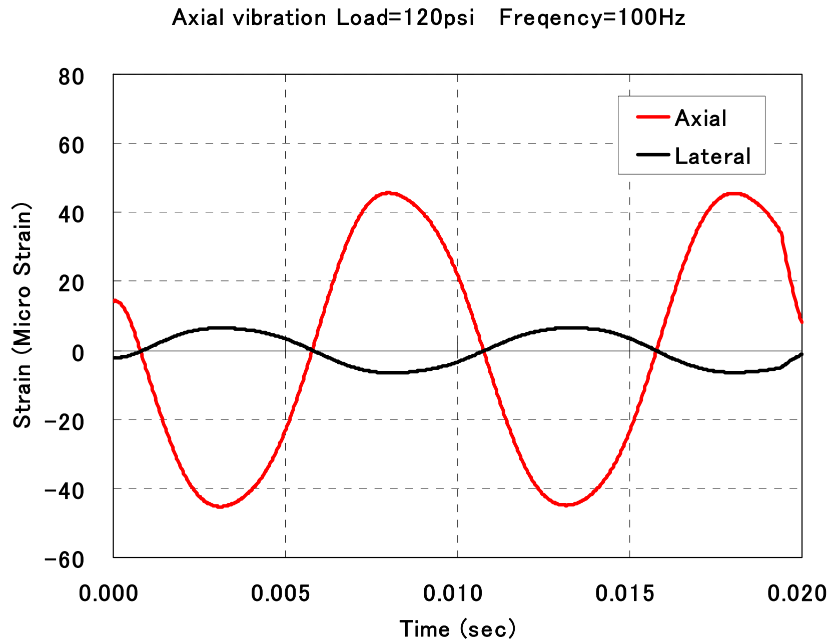


Figure 6. Monitored waveform of axis lateral

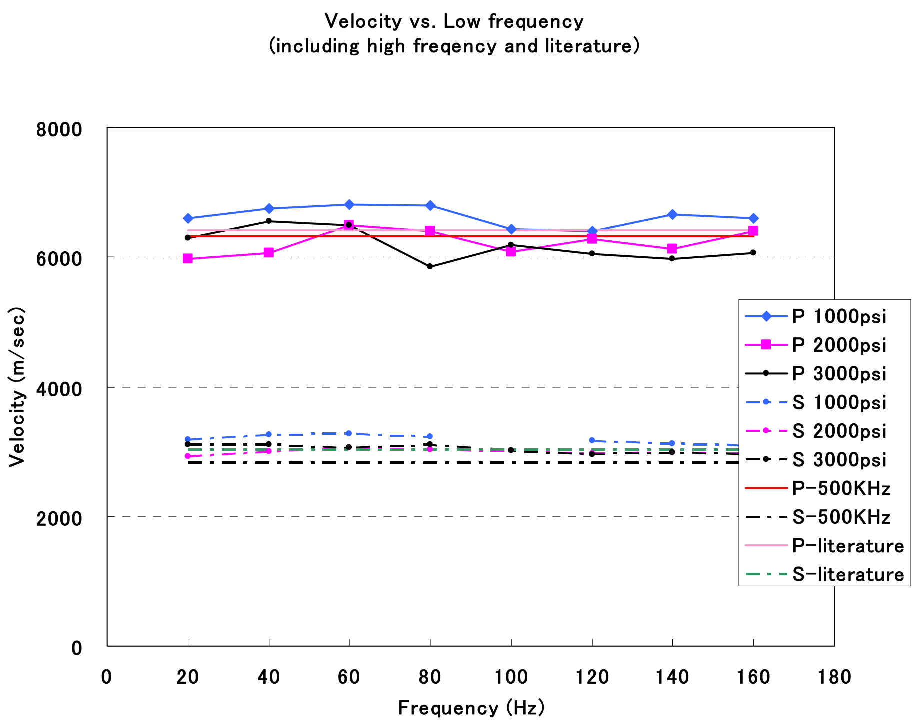


Figure 7. Relationship of velocity vs. Low frequency