Study on Ultrasonic Measurement System to Detect Penetration of Boulders

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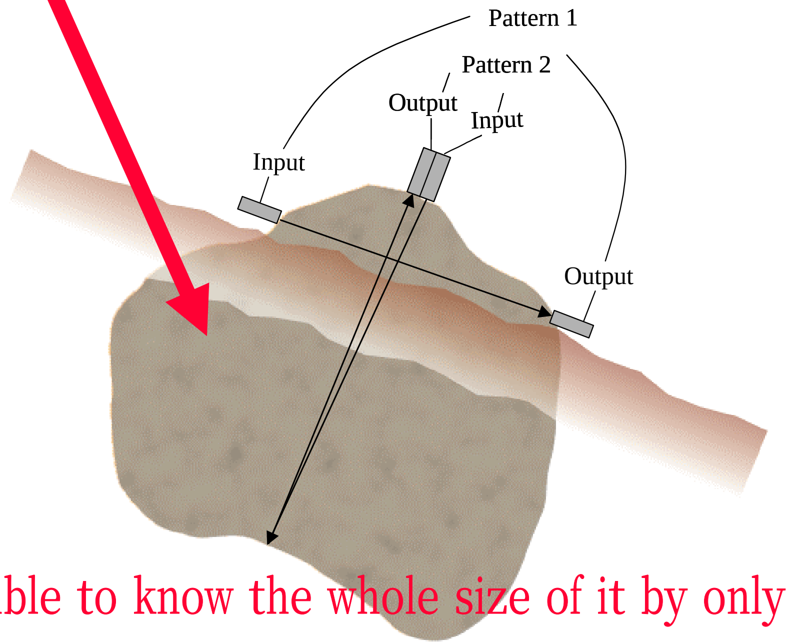
What is a Boulder Stone

Boulder stone



Impossible to know the whole size of it by only looking

Bo

sep

buried under the surface

Boulder stone

Earthquake

Fallen rocks

Crisis of life and wealth

Detect penetration of boulder and evaluation of volume

Introduction

Typically nondestructive tests are used to investigate the degree of damage and length of the natural and artificial construction. The

Theoretically, if it becomes possible to input vibration of an ultrasonic domain into an object with a high output directly to measure the arrival time of its reflection wave, the depth of the object will be measured with high precision.

shallow region of the object ca investigated. Elastic impact wave method is suitable for inv gating deeply penetrating structure such as a foundation p . Although, it is not suitable to investigate the minu hammer is used in the elastic impact w ossible to give a certain frequency to e, this test method has low precision.

Our Research

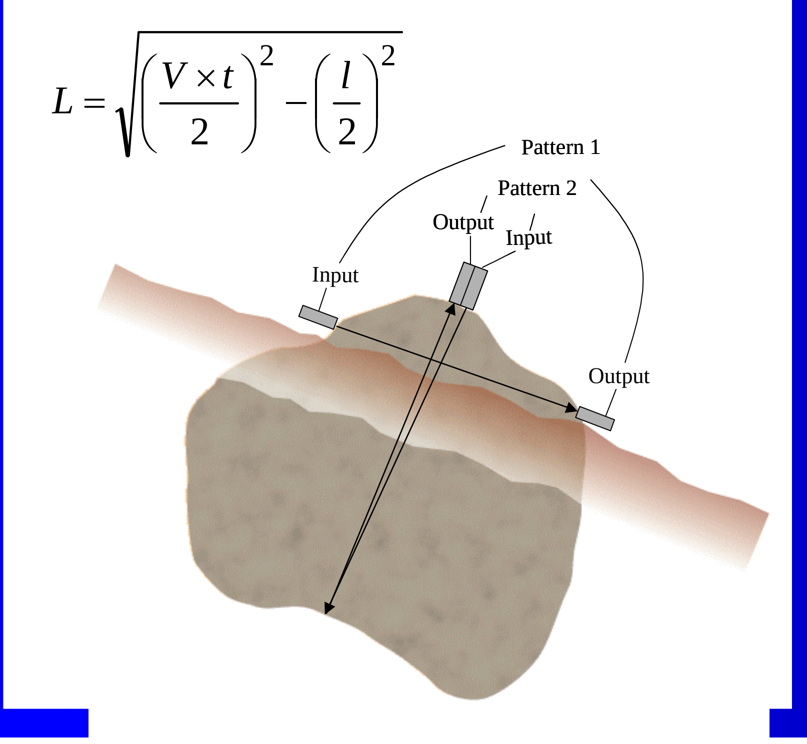
Device:Piezo Electric

Analyses:Autocorrelation

:Cepstrum

General Outline of our Method

The purpose of this research is to construct a measurement system for detecting the penetration of boulders with a high precision.



First Step

Calculate the ultrasonic velocity of the ultrasonic wave passing through a subject using the part of the boulder with a known length

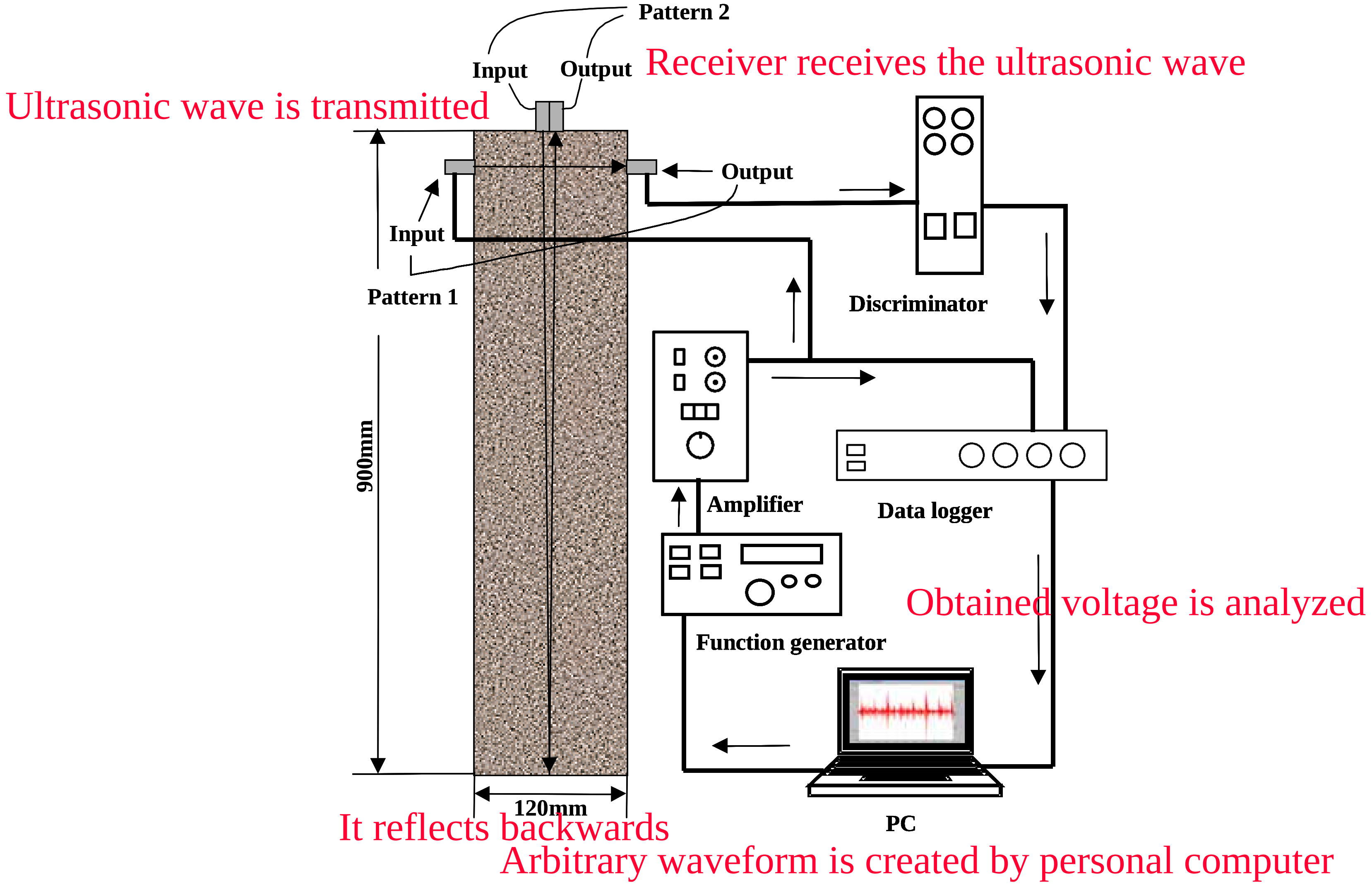
Second Step

Measure the arrival time of the reflection wave

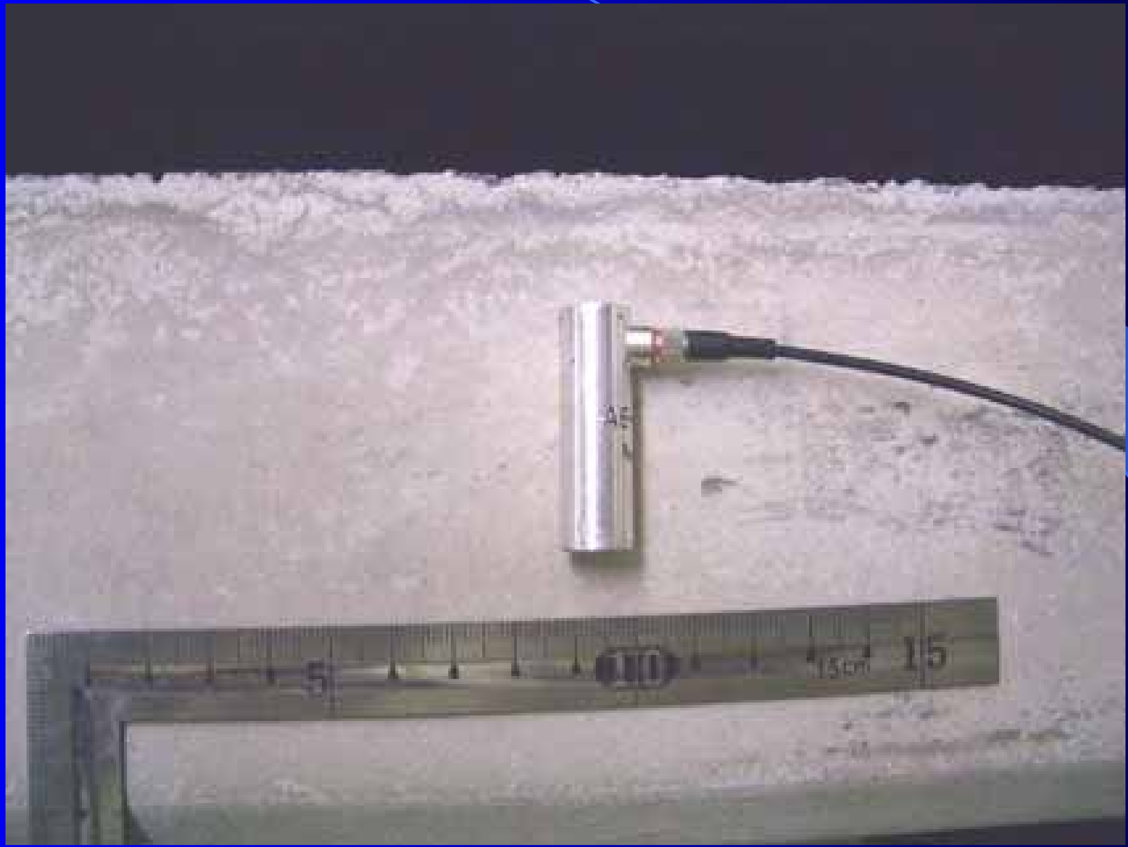
Third Step

Estimate the length of the boulder using the ultrasonic velocity calculated and the arrival time of the reflection wave

Schematic of Experimental Setup

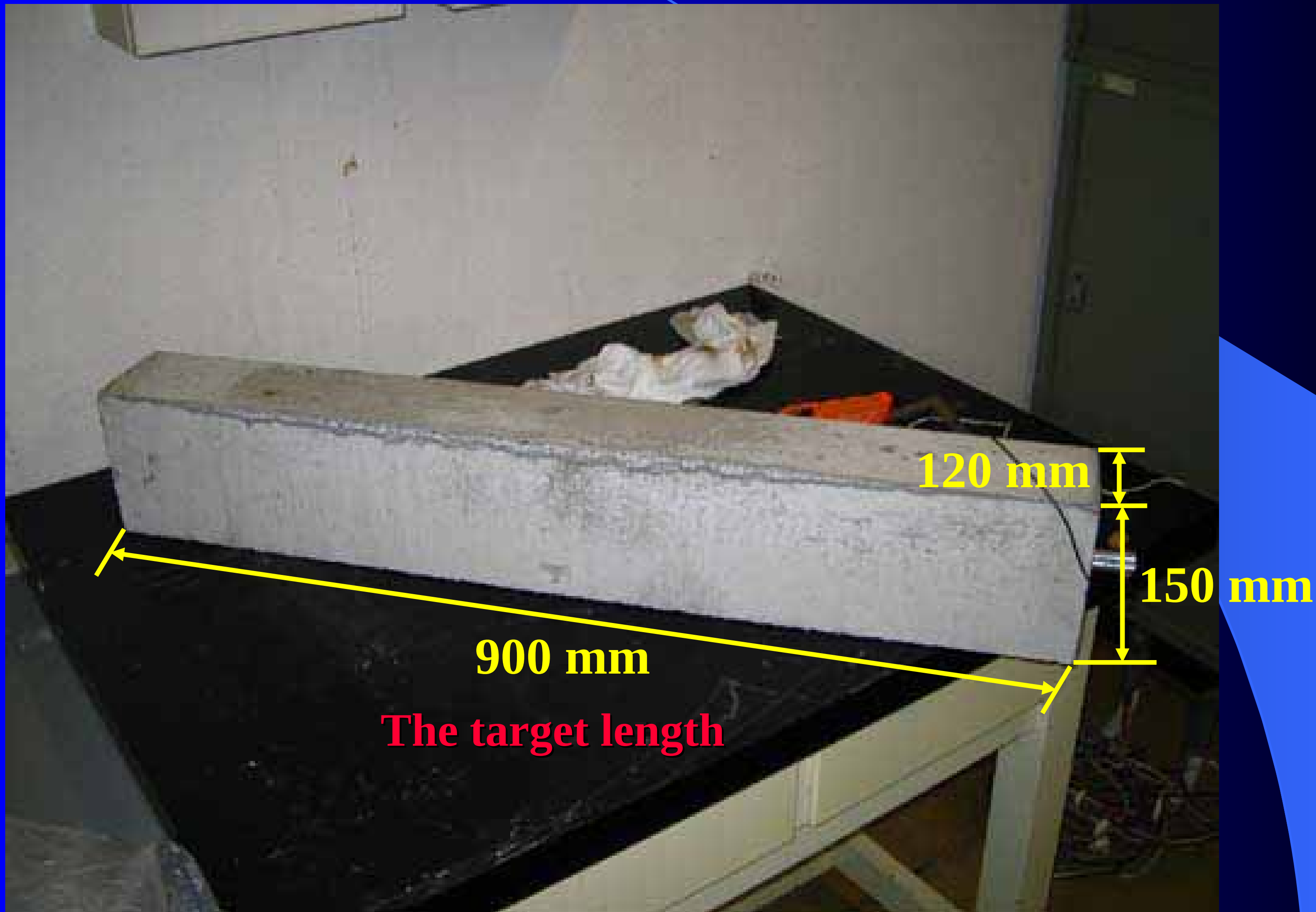


Picture of AE Transducers

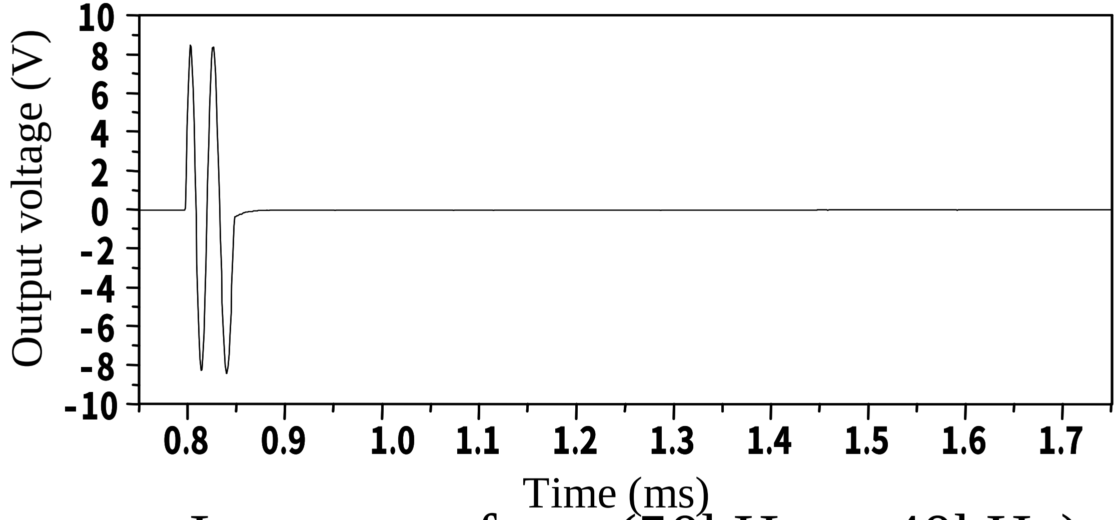


Resonance frequency 140kHz

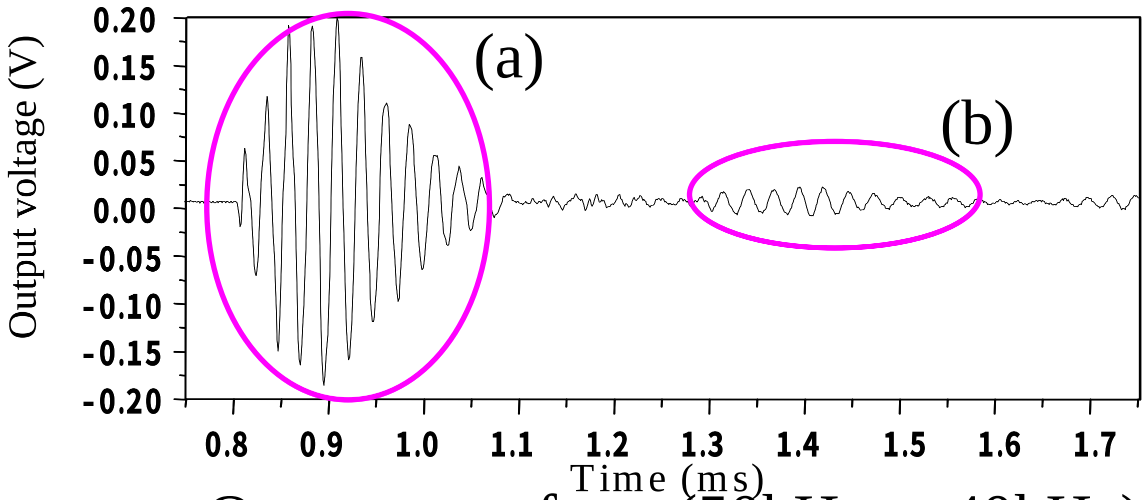
The Size of a Concrete Block



Case of Ideal Waveform

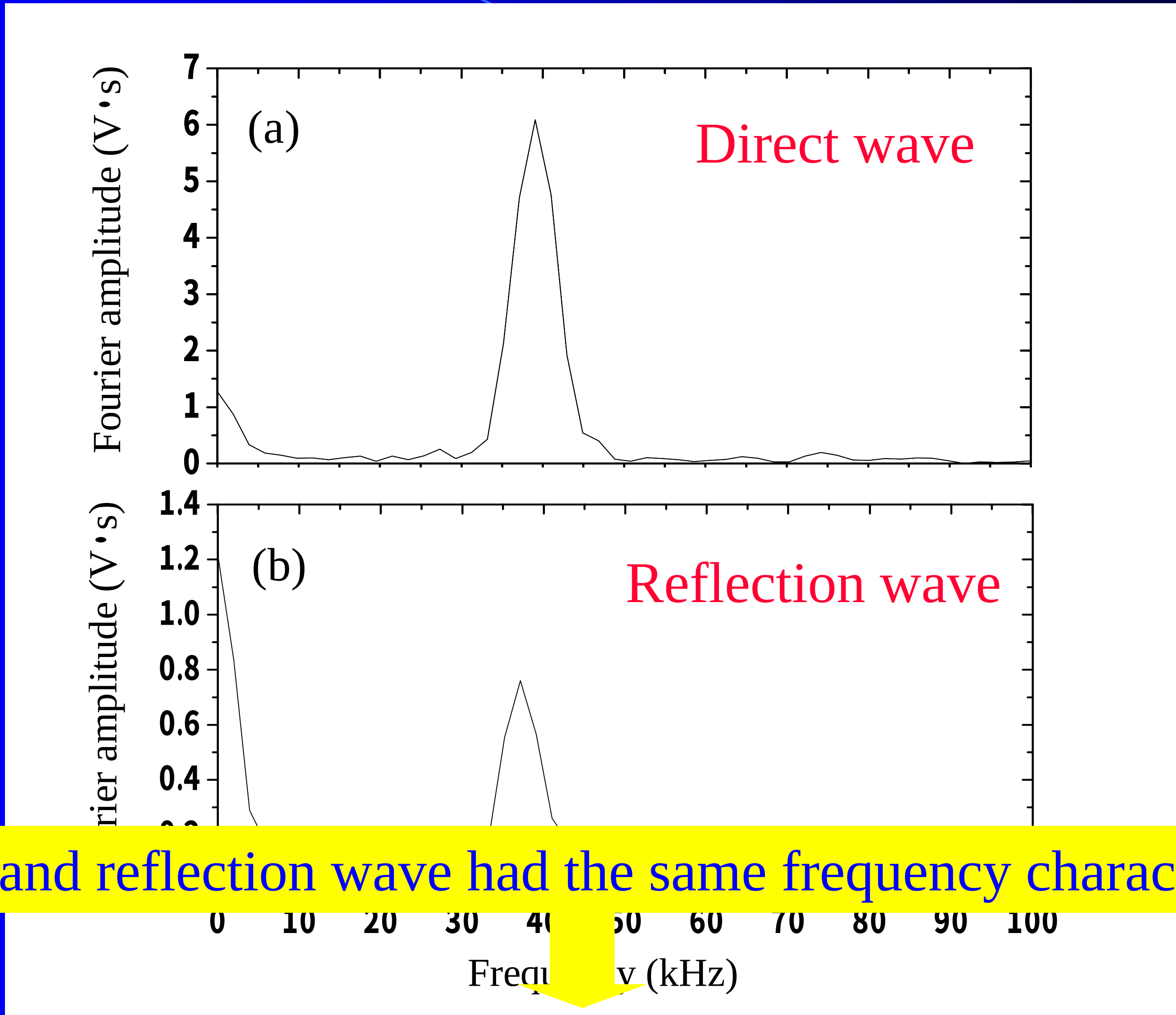


Input waveform (50kHz to 40kHz)



Output waveform (50kHz to 40kHz)

Result of FFT Analysis against Direct Wave and Reflection Wave



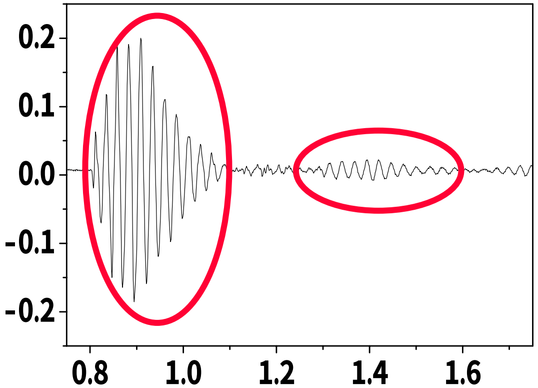
Direct wave and reflection wave had the same frequency characteristics!

Autocorrelation analysis can be used to obtain the arrival time of the reflection wave

Auto-correlation Analysis

Auto-correlation function

Ideal waveform



$$R_{ff}(j) = \frac{1}{N} \sum_{i=0}^{N-1} |x_i| \times |x_{i+j}| \qquad (1)$$

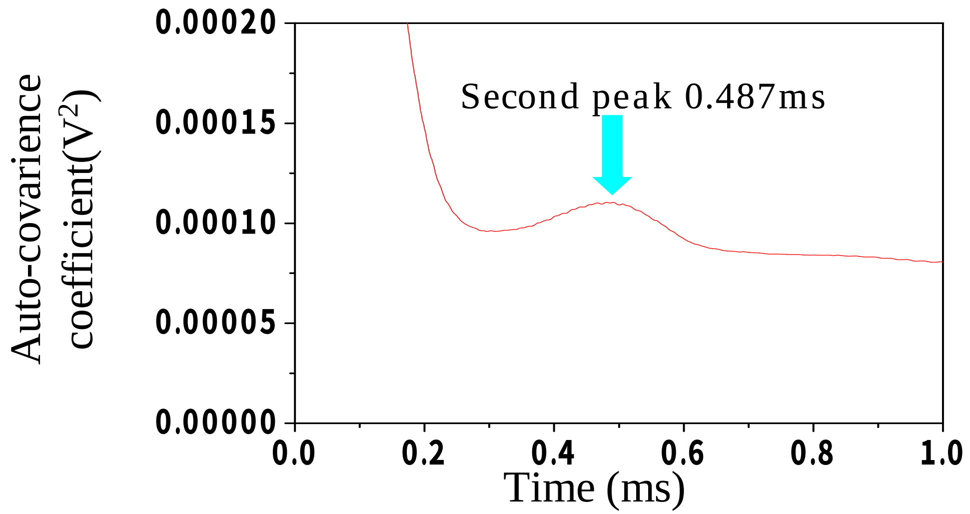
N : Number of data

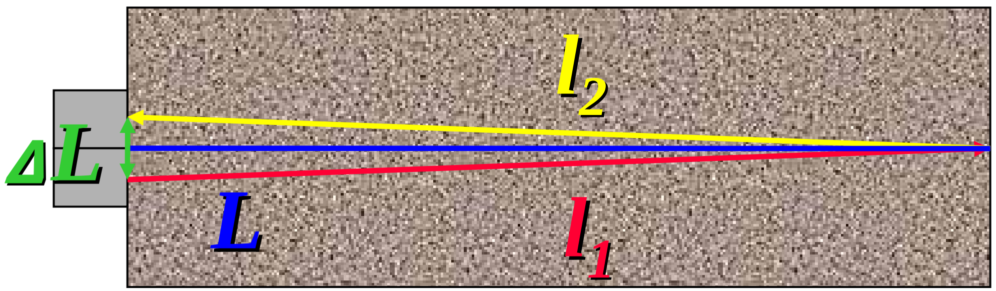
x_i : Amplitude of the i th data

x_{i+j} : Amplitude of $i+j$ th data

- Auto-correlation analysis is suitable for detecting the periodicity of the waveform.
- Receiver detects the direct wave, and next detects the reflection wave.
- The direct wave and the reflection wave had similar frequency characteristic.
- It is decided that auto-covariance coefficient R_{ff} (j) will have peak value at the time lag Δt.

Result of Auto Correlation Analysis





$$L \approx (l_1 + l_2)/2 = V \times t/2$$

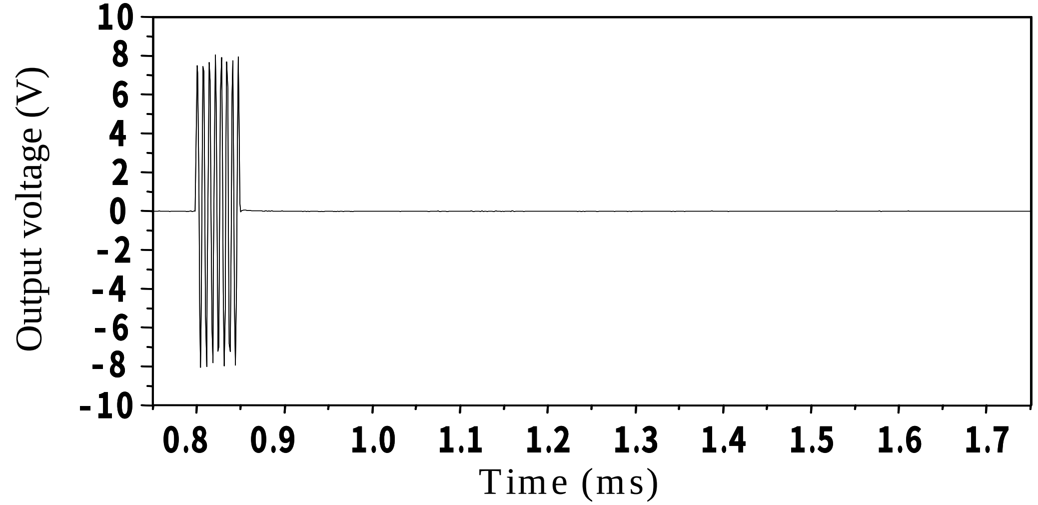
$$L = 3688.52 \times 0.487/2$$

$$= 898.15[mm]$$

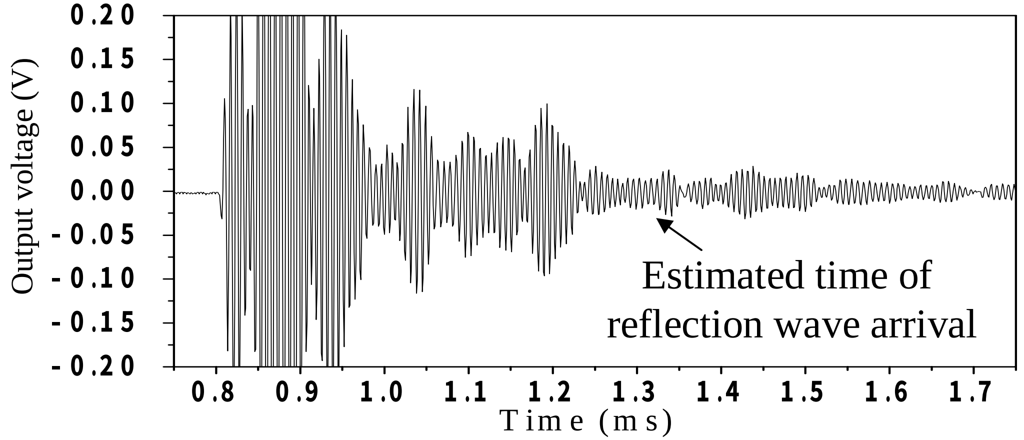
$$\text{Error} : 900 - 898.15 = 1.85[mm]$$

$$\text{Measurement Error} : 0.20\%$$

Case of General Waveform



Input waveform (150kHz to 140kHz)



Output waveform (150kHz to 140kHz)

Detecting Reflection Wave by Using Power Cepstrum Analysis

The formula which a direct wave and a single reflection wave add

$$y(t) = x(t) + r \cdot x(t - T)$$

Power Spectrum

$$|Y(j\omega)|^2 = |X(j\omega)|^2 \left|1 + r \cdot e^{-jT\omega}\right|^2$$

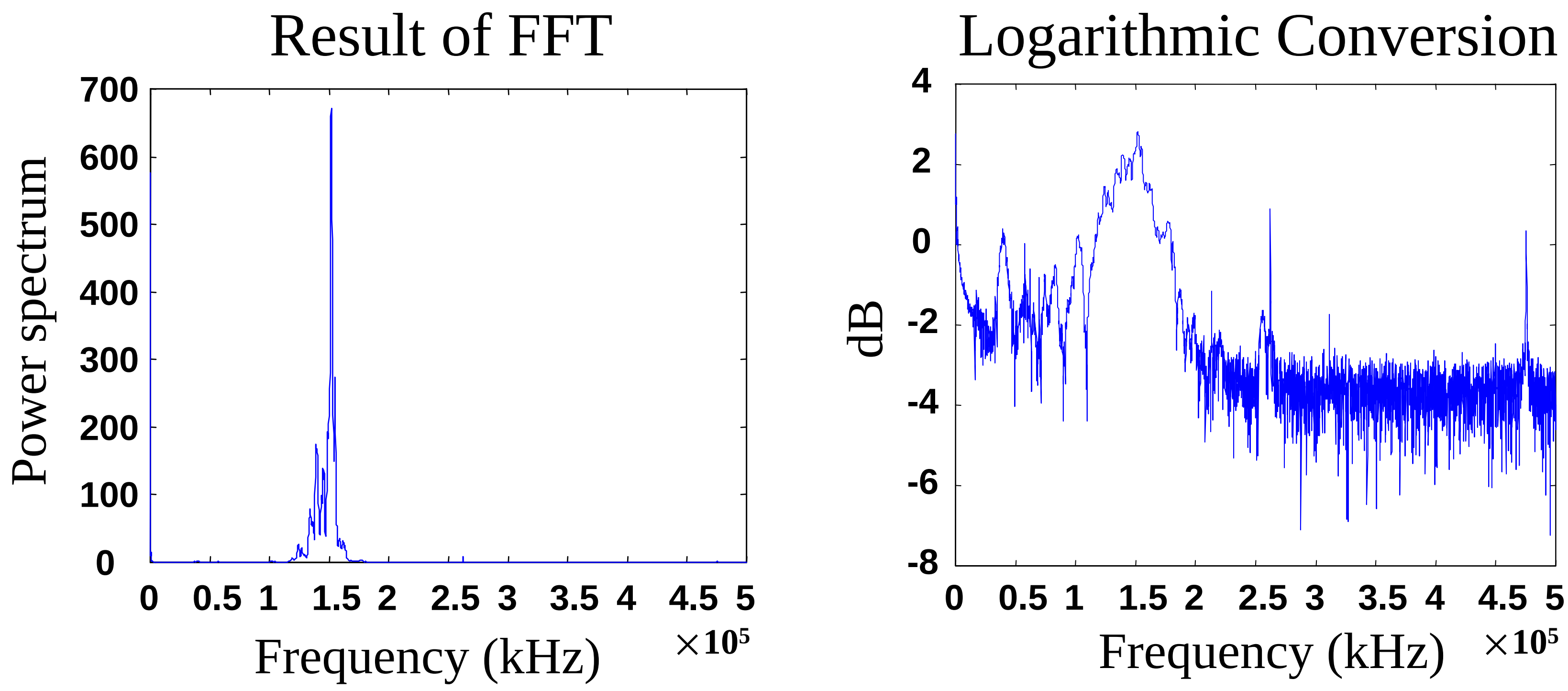
$$= |X(j\omega)|^2 \left(1 + r^2 + 2r\cos T\omega\right)$$

Logarithmic Conversion

$$\log|Y(j\omega)|^2 = \log|X(j\omega)|^2 + \log(1 + r^2) + \log(1 + \frac{2r}{1 + r^2}\cos T\omega)$$

T can be directly taken out of here when we apply the IFFT

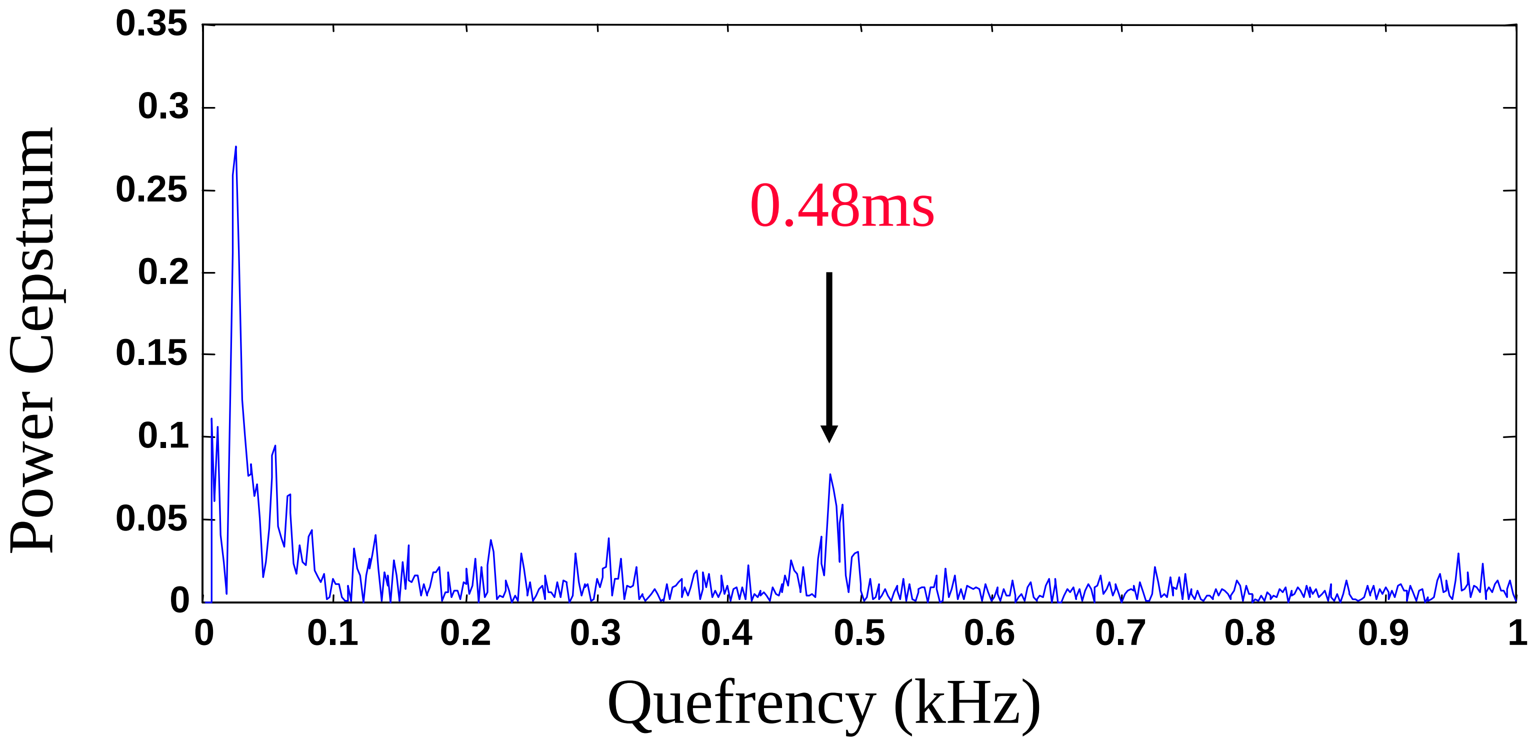
Result of Power Cepstrum Analysis ①



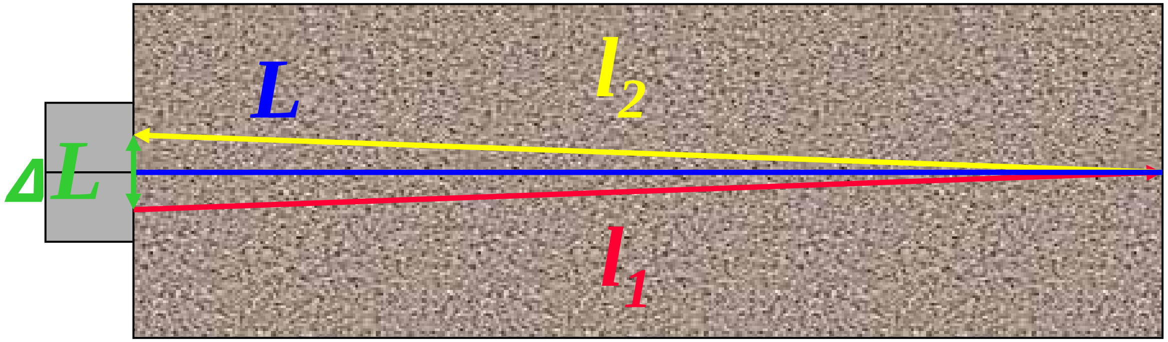
If received waveform include the reflection wave, when the power spectrum is taken logarithmic conversion, periodic ripple of cos($T\omega$) can be seen.

Result of Power Cepstrum Analysis ②

Frequency spectrum of the periodic ripple have the frequency that is 0.48ms



Estimate Length of a Concrete Block



$$L = \frac{\sqrt{(l_1 + l_2)^2 - \Delta L^2}}{2} = \frac{\sqrt{[V(t + \Delta t)]^2 - \Delta L^2}}{2} \approx V \times t / 2$$

$$L = 3688.52 \times 0.48 / 2$$
$$= 885.24 [mm]$$

$\text{Error} = 900 - 885.24 = 14.76 [mm]$

Measurement error : 1.67%

L : Estimation size $[mm]$

ΔL : Distance between AE transducers $[mm]$

V : Ultrasonic velocity in this concrete block $[m/s]$

t : Time of reflection wave arrival calculated by auto-correlation analysis $[ms]$

Δt : Time concerning direct wave reaching from transmitter to receiver $[ms]$

Conclusion

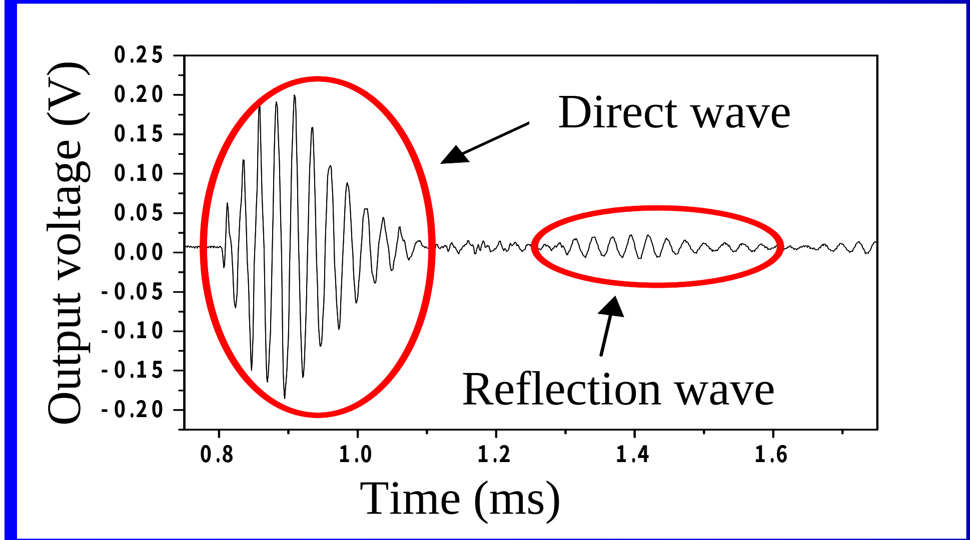
We have made an ultrasonic measurement system to detect penetration of boulders. Applied to concrete block as fundamental experiment, authors were able to obtain two kinds of output waves. One that contained a wave in which, the direct wave and the reflection wave were separated. The other that contained a wave in which, the direct wave and the reflection waves were mixed together.

Using our ultrasonic measurement system against the concrete block that length was 900mm, good result that have very little error within 2% was produced in both cases.

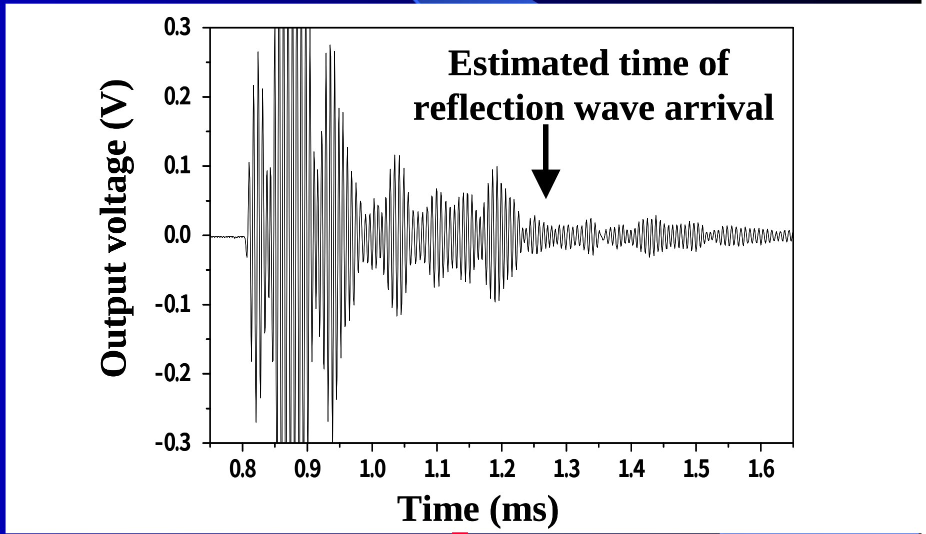
Analyses of this Research

Deep exploration
A powerful ultrasonic

Ideal waveform



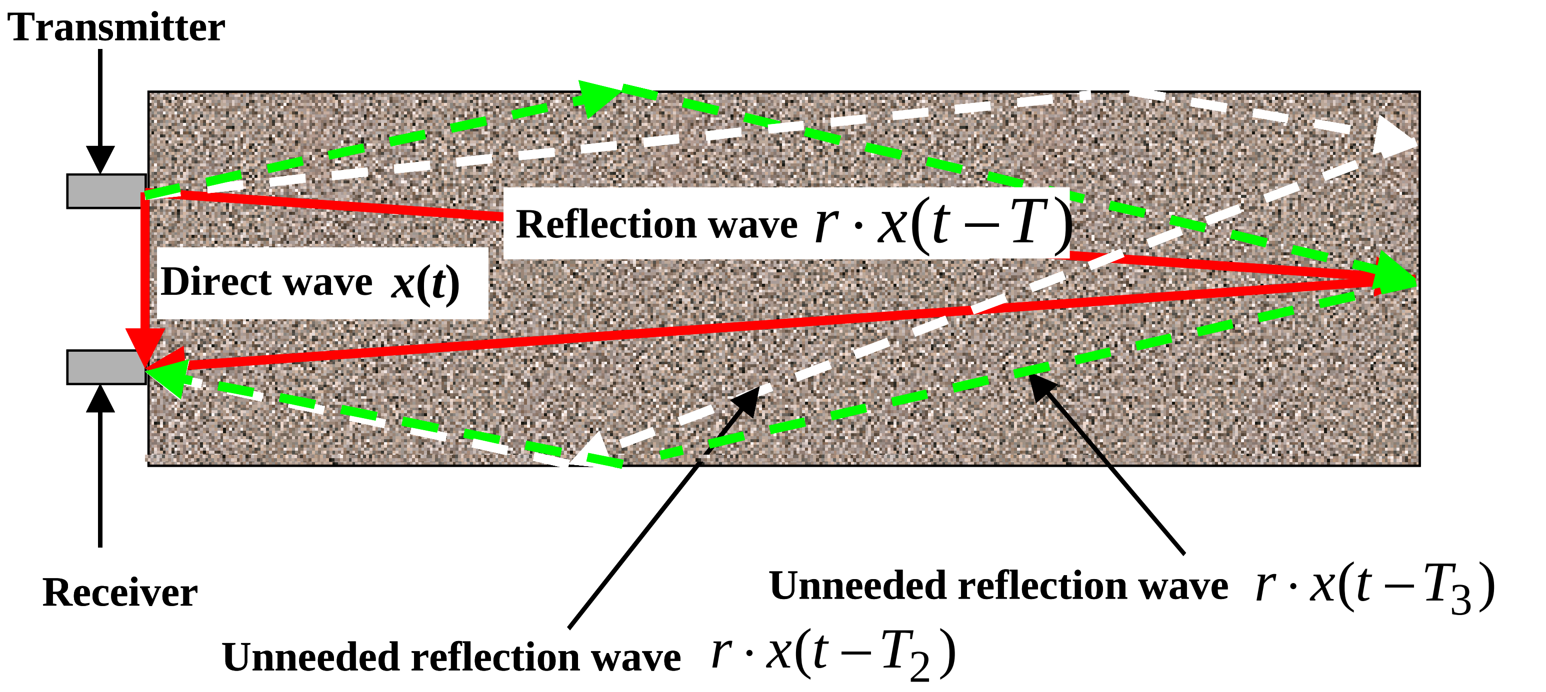
General waveform



Auto-correlation Analysis

Cepstrum Analysis

Relation of Direct Wave and Reflection Wave (Cepstrum Analysis)



r : rate of decrease

T : time lag

$r \cdot x(t-T)$: reflection wave

$y(t) = x(t) + r \cdot x(t-T)$

$g(t) = \delta(t) + r \cdot \delta(t-T)$: impulse response

$y(t) = x(t) * g(t)$

The Flow of Cepstrum Analysis

$$y(t) = x(t) * g(t)$$

↓ FFT

$$Y(\omega) = X(\omega) \cdot G(\omega)$$

↓ $\log Y(\omega)$

$$\log|Y(\omega)|^2 = \log|X(\omega)|^2 + \log|G(\omega)|^2$$

↓ IFFT

$$IFFT\left[\log|Y(\omega)|^2\right] = IFFT\left[\log|X(\omega)|^2\right] + IFFT\left[\log|G(\omega)|^2\right]$$