Purpose

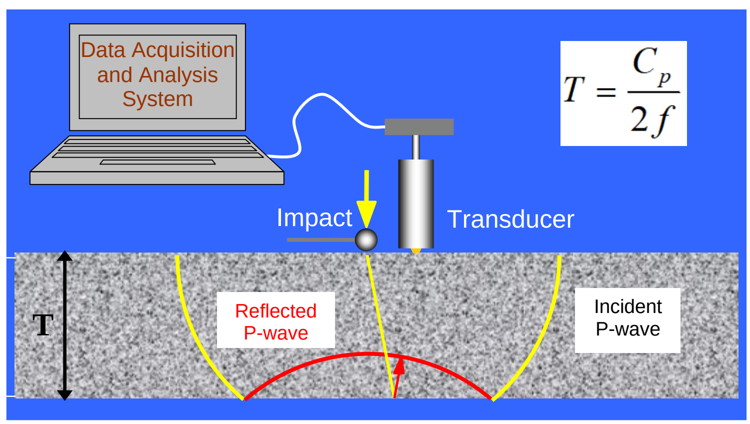
The use of traditional ultrasonic pulse velocity testers to identify the presence of anomalies in structures requires access to both faces of a member and it is not possible to determine the depth to anomalies. These drawbacks are eliminated by using the impact-echo method, which requires access to only one face. The impact-echo method is based on monitoring the periodic arrival of reflected stress waves and is able to obtain information on the depth of the internal flaws or the thickness of a solid member.

The **Mirador** is a versatile, portable system, empowered by **Echolyst** software (see datasheet), based on the impact-echo method, that can be used for the following applications:

- Measure the thickness of pavements, asphalt overlays, plate-like concrete elements like slabs or walls, etc.
- Detect the presence and depth of voids and honeycombing
- Detect voids below slabs-on-ground
- Evaluate the quality of grout injection in post-tensioning cable ducts or joints for precast elements
- Integrity of a membrane below an asphalt overlay protecting structural concrete
- Delamination surveys of bridge decks, piers, cooling towers, chimneystacks, etc.
- Detect debonding of overlays and patches
- Detect ASR damage and freezing-and-thawing damage
- Measure the depth of surface-opening cracks
- Estimate early-age strength development (with proper correlation)

Principle

A short-duration stress pulse is introduced into the member by a small mechanical impact. This impact generates stress waves that propagate away from the impact point. A surface wave (R-wave) travels along the top surface, and a P-wave and an S-wave travel into the member. In impact-echo testing, the P-wave is used to obtain information about the member.

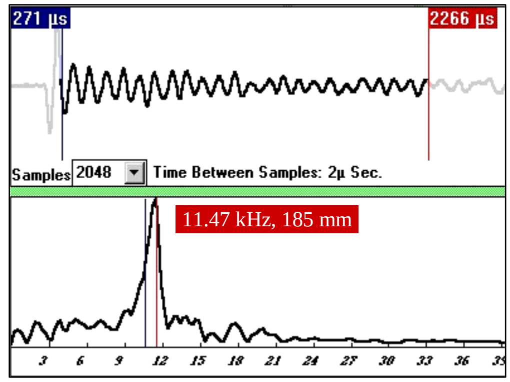


When the P-wave reaches the back side of the member, it is reflected and travels back to the surface where the impact was generated. A sensitive displacement transducer next to the impact point picks up the disturbance due to the arrival of the P-wave. The P-wave is then reflected back into the member and the cycle begins again. Thus, the P-wave undergoes multiple reflections between the two surfaces and the recorded waveform of surface displacement has a periodic pattern that is related to the thickness of the member and the wave speed.

The displacement waveform is transformed into the frequency domain to produce an **amplitude spectrum**, which shows the predominant frequencies in the waveform. The frequency of P-wave arrival is determined as the frequency with a high peak in the amplitude spectrum. The thickness (T) of the member is related to this thickness frequency (f) and wave speed (C_p) by the simple approximate equation shown on the image.

The same principle applies to reflection from an internal defect (delamination or void). Thus, the impact-echo method is able to determine the location of internal defects as well as measure the thickness of a solid member.

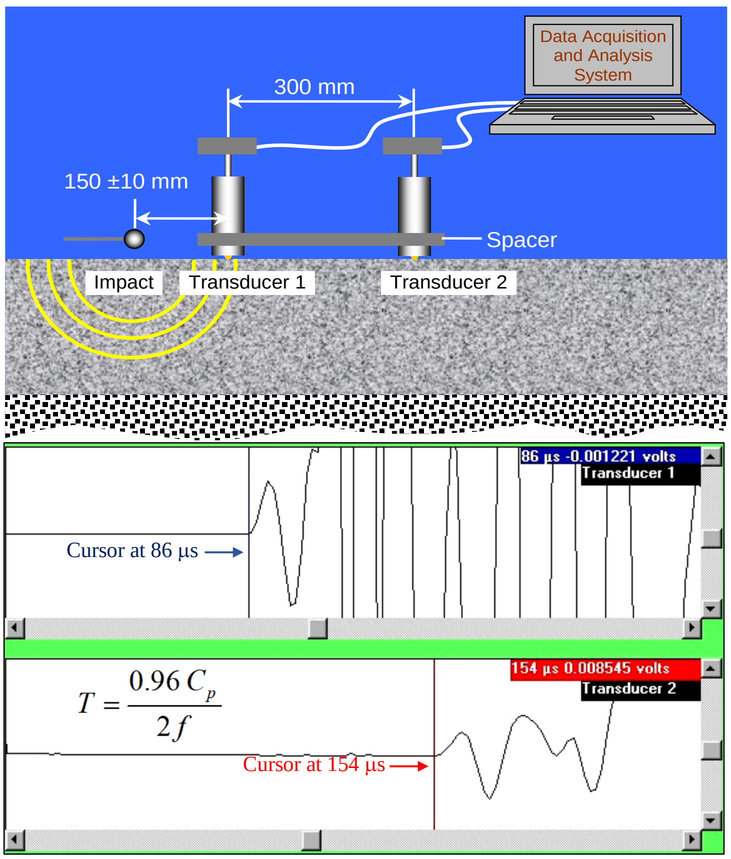
Example



The upper plot in this example shows the surface displacement waveform (displacement vs time) obtained from a test of a solid concrete slab. The figure below is the amplitude spectrum (amplitude vs frequency) obtained by transforming the waveform into the frequency domain by applying the Fast Fourier Transform algorithm. The peak at 11.47 kHz (red cursor) is the thickness frequency. For a measured wave speed of 4240 m/s, this frequency corresponds to a thickness of:

$$4240/(2\times 11{,}470) = 0.185 \text{ m, or } 185 \text{ mm.}$$

Thickness Measurement by ASTM C1383



Accurate measurement of thickness requires knowledge of the in-place P-wave speed. ASTM C1383, "Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method," permits two methods for obtaining the P-wave speed. One method is by determining the thickness frequency and then measuring the actual plate thickness at that point. The equation in this case is solved for C_p, i.e., $\boldsymbol{C_p = 2\, f\, T}$.

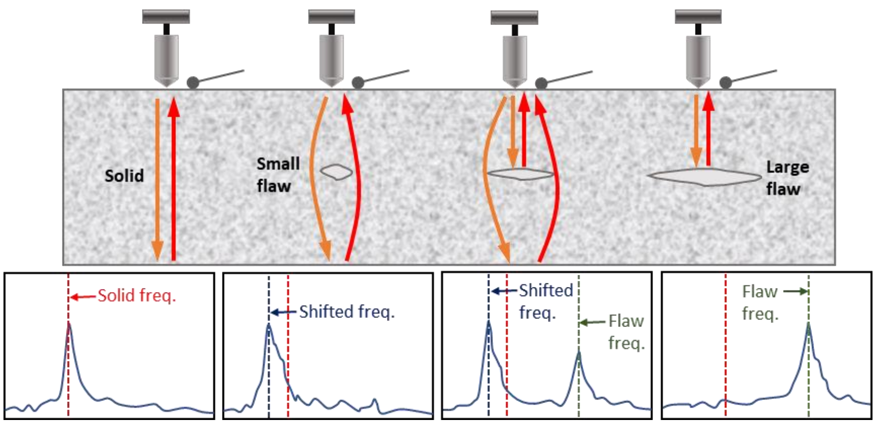
Alternatively, C_p can be determined by measuring the time for the P-wave to travel between two transducers with a known separation. With the **LONGSHIP** assembly, the transducers are placed 300 mm apart and the impactor is about 150 mm from one of the transducers one the line passing through the transducers. The distance L (300 mm) between the transducers, is divided by time difference Δt between arrival of the P-wave at the second and first transducers. In the figure on the left, Δt was measured to be 154 – 86 = 67 µs, and the P-wave speed is 0.3/0.000067 = 4480 m/s. If the wave speed is determined by the surface measurement method, the resulting value is multiplied by 0.96 when it used to calculate thickness [1].

Detection of Internal Defects

The P-wave generated by impact will reflect at interfaces within the concrete where there is a change in **acoustic impedance**, which is defined as the product of the density and wave speed of a material. The following table lists the reflection coefficients of a P-wave travelling through concrete and incident normal to an interface with air, water, soil, or steel. A negative reflection coefficient means that the stress changes sign when the stress wave is reflected; for example, a compressive stress would be reflected as a tensile stress. Steel is "acoustically harder" than concrete and the stress does not change sign when reflected at a concrete-steel interface.

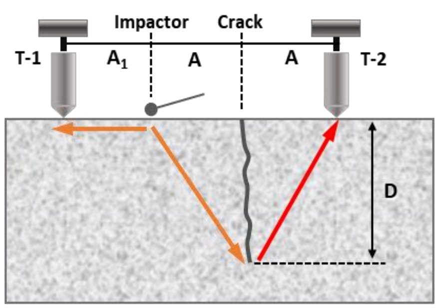
Interface	Reflection Coefficient
Concrete-air	-1.0
Concrete-water	-0.65 to -0.75
Concrete-soil	-0.3 to -0.9
Concrete-steel	0.65 to 0.75

It is seen that at a concrete-air interface, there is complete reflection of the P-wave (1.0 = 100%). This makes the impact-echo method inherently powerful for detecting air interfaces, such as those due to cracks, delaminations, cavities, and honeycombed concrete. If the area of the reflecting interface is large, the impact-echo response will be similar to that of a solid plate except that the thickness frequency will be shifted to the higher value corresponding to the depth of the interface. If the defect is just large enough to be detectable, the amplitude spectrum will show two peaks: a high frequency peak corresponds to reflection from the interface and the low frequency peak corresponds to the portion of the P-wave that travels around the defect and reflects from the opposite surface of the plate. The frequency associated with the portion of the P-wave that travels around the defect will be shifted to a lower frequency value than the solid plate thickness frequency. This is because the wave has to travel a longer distance as it diffracts around the flaw. The frequency shift is a good indicator of the presence of a flaw if it is known that the plate thickness is constant.

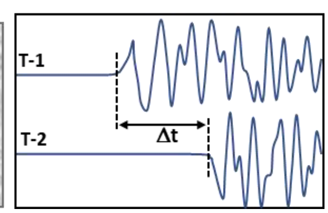


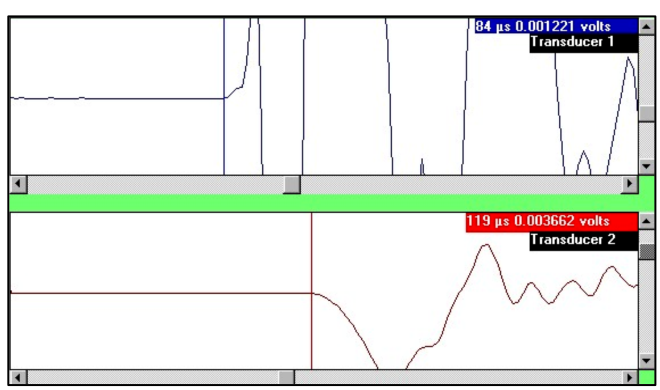
Depth of Surface-Opening Cracks

The **Mirador** can also be used to measure the depth of surface-opening cracks, using a time domain analysis. The **LONGSHIP** is used with the transducers on opposite sides of the crack and the impact is generated on the line passing through the transducers. When the P-wave reaches the tip of the crack, the crack tip acts as a P-wave source by **diffraction**. The diffracted P-wave is detected by the second transducer on the opposite side of the crack. By measuring the time interval between the arrival of the direct P-wave at the first transducer and the arrival of the diffracted wave at the second transducer, the depth of the crack can be calculated. The example shown is from testing a fire-damaged structure, and a crack depth of 87 mm was estimated for a time difference (Δt) of 35 μs and a P-wave speed of 3155 m/s.



$$D = \sqrt{\frac{(C_p + \Delta t + A_1)^2}{4} - A^2}$$





Mirador

Testing Examples

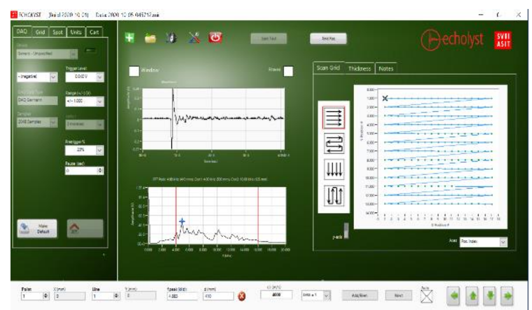
Detection of delaminations and honeycomb in sewer pipe

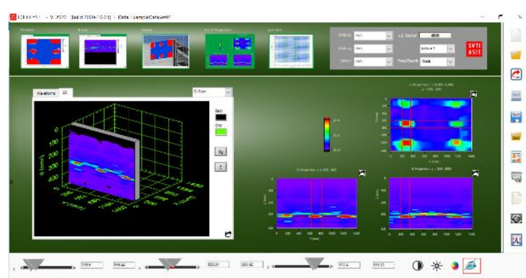
Measurement of P-wave speed by surface method

Testing for quality of grout injection in cable ducts

Mirador Specifications

Echolyst screenshots





- Data Acquisition System:
  - 2 channels, 4 MB/channel
  - 8 bits resolution, 50 MHz bandwidth
  - -5V to 5V Input Voltage Range
  - USB interface
- Dry contact, high sensitivity, piezoelectric handheld transducers
- Equipped with **Echolyst** software that allows:
  - real-time waveform display while testing
  - create 2-D and 3-D visual representations
  - look at reflecting interface on different cutting planes
  - audio assisted prompts to speed up data acquisition
  - superimpose test results on real image of test location
  - report generation
- Accuracy (assuming a constant P-wave speed):
  - Thickness measurement, direct calibration: ± 2%
  - Thickness measurement by surface P-wave speed measurement: ± 3%
  - Depth of surface-opening cracks: ± 4%
- Operating conditions: Temperature: -10 to 50 °C, RH ≤ 95 %

Marador Ordering Numbers

Mirador-3000	Mirador-5000
With **Echolyst** Software and one Mark IV transducer for flaw detection and thickness measurements. Can be later upgraded to Mirador-5000	With **Echolyst** Software and **LONGSHIP** assembly with two Mark IV transducers for flaw detection, thickness measurement, crack depth measurement, and P-wave speed measurement according to ASTM C1383.

Mirador -3000

Item	Order #
Laptop computer	MRD-10
Data acquisition module with USB cable	MRD-20
Echolyst software	MRD-30
Mark IV transducer	MRD-40
Star support with 5, 8 and 12 mm impactors	MRD-60
Impactors on spring rods, 5, 8, and 12 mm	MRD-70
Protection caps for transducer tips, 4 pcs	MRD-80
BNC cable	MRD-90
User Manual for **Echolyst** software	MRD-150
Operation manual	MRD-160
Attaché case	MRD-120

Mirador-5000

Item	Order #
Laptop computer	MRD-10
Data acquisition module with USB cable	MRD-20
Echolyst software	MRD-30
Viking **LONGSHIP** with long handle and two Mark IV handheld transducers	MRD-50
Star support with 5, 8 and 12 mm impactors	MRD-60
Impactors on spring rods, 5, 8, and 12 mm	MRD-70
Short handle for crack depth measurement	MRD-80
Protection caps for transducer tips, 8 pcs	MRD-90
BNC cable, 2 pcs.	MRD-100
Manual for **Echolyst** software	MRD-150
Operation manual	MRD-160
Attaché case	MRD-130

Optional Items

Spider, Order # MRD-210

The **Spider** contains 8 spherical impactors, with diameters ranging from 2 mm to 15 mm and covering a frequency content from approximately 1.2 kHz to 100 kHz on a hard concrete surface.

References

[1] The explanation for the 0.96 factor can be found in: Gibson, A. and Popovics, J.A., 2005, "Lamb Wave Basis for Impact-Echo Method Analysis," *J. of Engineering Mechanics* (ASCE), Vol. 131, No. 4, pp. 438-443.