Purpose

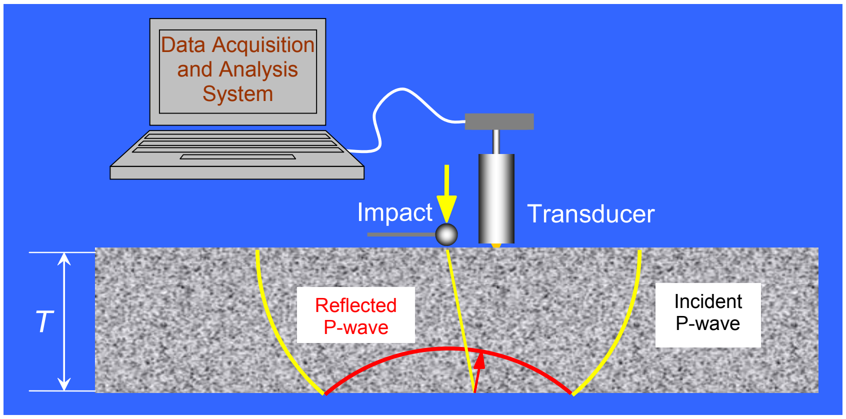
The use of traditional stress wave methods, such as ultrasonic through transmission (pg. 123), to identify the presence of anomalies in structures requires access to both faces of a member. Furthermore, it is not possible to determine the depth to anomalies. These drawbacks are eliminated by using the impact-echo method, which requires access to only one surface. 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 reflecting interface or the thickness of a solid member.

The **DOCter** is a versatile, portable system based on the impact-echo method, and can be used for the following applications:

- Measure the thickness of pavements, asphalt overlays, slabs-on-ground and walls
- 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
- Integrity of a membrane below an asphalt overlay protecting structural concrete
- Delamination surveys of bridge decks, piers, cooling towers and chimneystacks
- 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 mechanical impact. This impact generated three types of 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. The recorded waveform of surface displacement has a periodic pattern that is related to the thickness of the member and the wave speed.

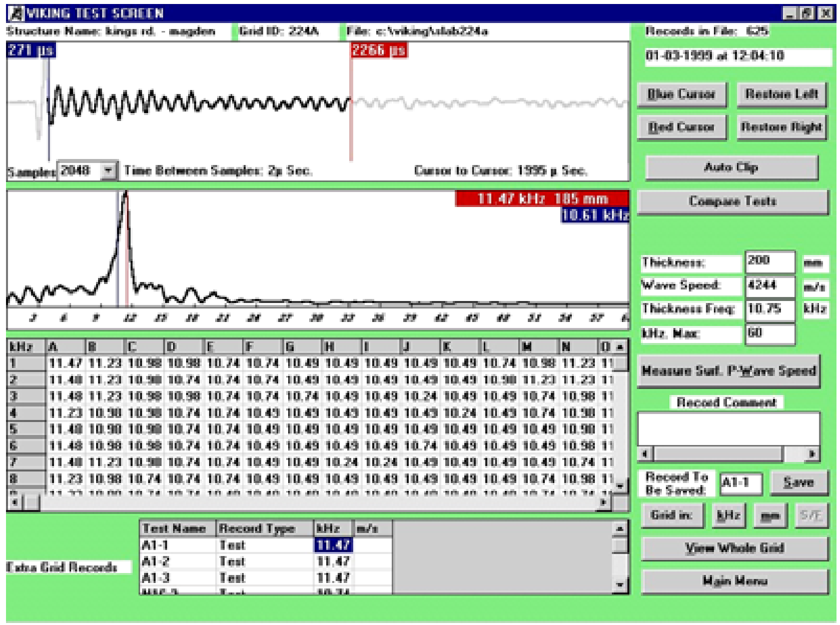
The displacement waveform is transformed into the frequency domain to produce an **amplitude spectrum**, which shows the predominant frequencies in the waveform. The frequency of P-wave arrival is determined as the frequency with a high peak in the amplitude spectrum. The thickness (T) of the member is related to this thickness frequency (f) and wave speed (C_p) by this simple approximate equation (see also pg. 51):

$$T = \frac{C_p}{2f}$$

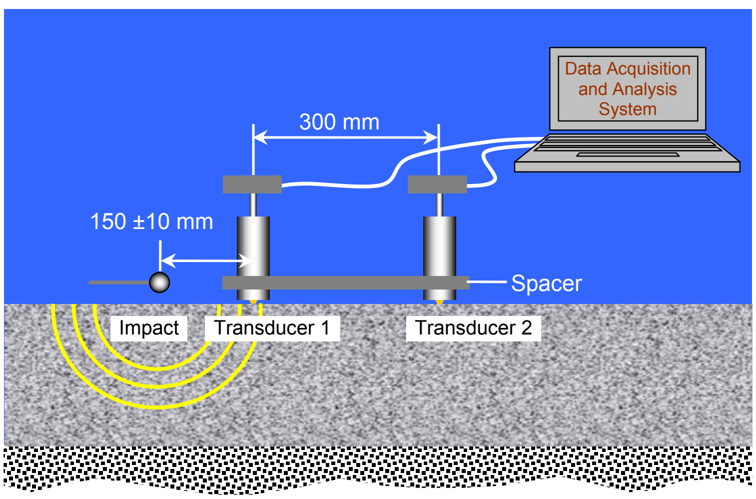
The same principle applies to reflection from an internal defect (delamination or void). Thus, the impact-echo method is able to determine the location of internal defects as well as measure the thickness of a solid member.

Example

The upper plot in this example shows the surface displacement waveform obtained from a test of a solid concrete slab. The figure below the waveform is the amplitude spectrum obtained by transforming the waveform into the frequency domain. The peak at 11.47 kHz is the thickness frequency. For a wave speed of 4240 m/s, this frequency corresponds to a thickness of 4240/(2×11,470) = 0.185 m, or 185 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 on page 50 is used to solve for C_p, i.e., $C_p = 2\, f\, T$.

Alternatively, C_p may be determined by measuring the time for the P-wave to travel between two transducers with a known separation. With the **LONGSHIP** two-transducer 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 shown on the next page, Δt was measured to be 67 µs, and the P-wave speed is 0.300 / 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. Thus the correct equation for thickness calculation is:

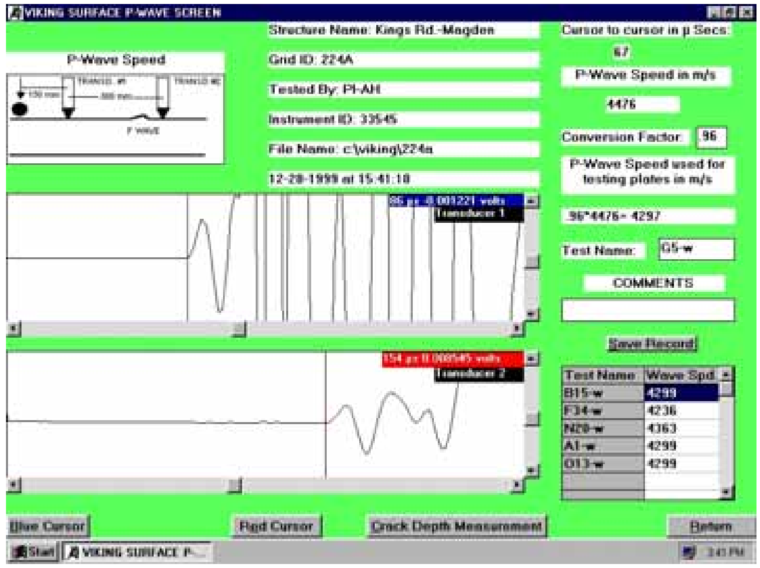
$$T = \frac{0.96\, C_p}{2 f}$$

The explanation for this 0.96 factor can be found in the following reference:

Gibson, A. and Popovics, J.A., 2005, "Lamb Wave Basis for Impact-Echo Method Analysis," *J. of Engineering Mechanics* (ASCE), Vol. 131, No. 4, April, pp. 438-443.

Measurement of P-wave Speed

The figure to the right is an example of the measurement of P-wave speed by using two transducers a known distance apart. The time of arrival of the P-wave at each transducer is determined as the point when the signal for each transducer rises above the background value. The **Viking** software allows the user to place cursors at the points corresponding to the P-wave arrivals, and calculates the value of C_p. In this case, the calculated speed is 4480 m/s, and 96 % of this value is 4300 m/s.



Detection of Internal Defects

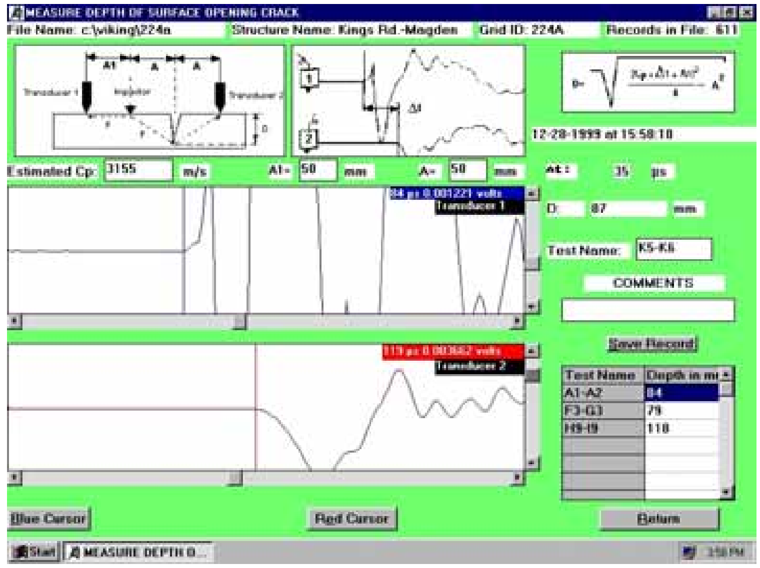
The P-wave generated by impact will reflect at interfaces within the concrete where there is a change in **acoustic impedance**, which is defined as the product of the density and wave speed of a material. The following lists the reflection coefficients of a P-wave travelling through concrete and incident normal to an interface with air, water, soil, or steel:

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

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.

It is seen that at a concrete-air interface, there is complete reflection of the P-wave. This makes the impact-echo method inherently powerful for detecting air interfaces, such as those due to 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. By positioning the cursor at the frequency associated with the flaw, the flaw depth is shown by the **Viking** software. 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 **DOCter** can also be used to measure the depth of surface-opening cracks, using a time domain analysis. The **LONGSHIP** transducers are placed on opposite sides of the crack (as shown in the sketch to the right) and 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, a process called **diffraction**. The diffracted P-wave is detected by the transducer on the opposite side of the crack from the impact. 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 of 35 µs and a P-wave speed of 3155 m/s.

Accuracy

For P-wave speed determined by calculation from a test at a point of known thickness, the error in thickness measured by the **DOCter** system is estimated to be within ± 2 %. This assumes that the same P-wave speed is applicable at all test points.

In the case of thickness measurement based on measuring the P-wave speed from surface measurements, the error in thickness dues to systematic errors associated with the digital nature of the measurements is about ± 3 %. This assumes that the P-wave speed is uniform with depth.

The depth of surface-opening cracks can be estimated within ± 4 %.

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 located by ground penetrating radar

DOCter Ordering Numbers

The **DOCter** comes in two versions: the **DOC-700** for flaw detection and thickness measurement; and the **DOC-4000** for flaw detection, thickness measurement, crack depth measurement, and P-wave speed measurement**.** The **Spider** multiple impactor unit can be purchased as an option to increase the operating range of the systems.

DOC-700

The **DOC-700** system is a one-channel system for thickness measurement and flaw detection. The P-wave speed is determined by testing over a solid portion of a plate with known thickness. The system includes a laptop computer, a data acquisition module, one Mark IV transducer with impactors, and software. The hardware components and computer are delivered in attaché cases (not shown).

Item	Order #
Laptop computer	DOC-10
Data acquisition module with USB cable	DOC-20
Viking software, CD-ROM Data	DOC-30
Mark IV transducer	DOC-40
Star support with 5, 8 and 12 mm impactors	DOC-60
Impactors on spring rods, 5, 8, and 12 mm	DOC-70
Protection caps for transducer tips, 4 pcs	DOC-80
Single cable	DOC-90
Attaché case for Mark IV transducer	DOC-120
Attaché case for laptop computer	DOC-140
Manual for **Viking** software	DOC-150
Operation manual for DOC-700 system	DOC-160
Testing case studies	DOC-170

DOC-4000

The **DOC-4000** system is a two-channel system that complies with the surface method for P-wave speed measurement given in ASTM C1383. Besides thickness determination and flaw detection, the **DOC-4000** can be used to estimate the depth of surface-opening cracks.

Item	Order #
Laptop computer	DOC-10
Data acquisition module with USB cable	DOC-20
Viking software, CD-ROM Data	DOC-30
Viking **LONGSHIP** with long handle and two Mark IV handheld transducers	DOC-50
Star support with 5, 8 and 12 mm impactors	DOC-60
Impactors on spring rods, 5, 8, and 12 mm	DOC-70
Short handle for crack depth measurement	DOC-80
Protection caps for transducer tips, 8 pcs	DOC-90
Double cable	DOC-100
Attaché case for **LONGSHIP**	DOC-130
Attaché case for laptop computer	DOC-140
Manual for **Viking** software	DOC-150
Operation manual for DOC-4000 system	DOC-160
Testing case studies	DOC-170

Spider, Order # DOC-210

The optional **Spider** contains 8 spherical impactors, with diameters ranging from 2 mm to 15 mm. The frequency content covered by the **Spider** impactors is approximately 1.2 kHz to 100 kHz on a hard concrete surface. The **Spider** is placed adjacent to the Mark IV transducer as shown in the photo.