Impact Echo (IE)

Target of Investigation

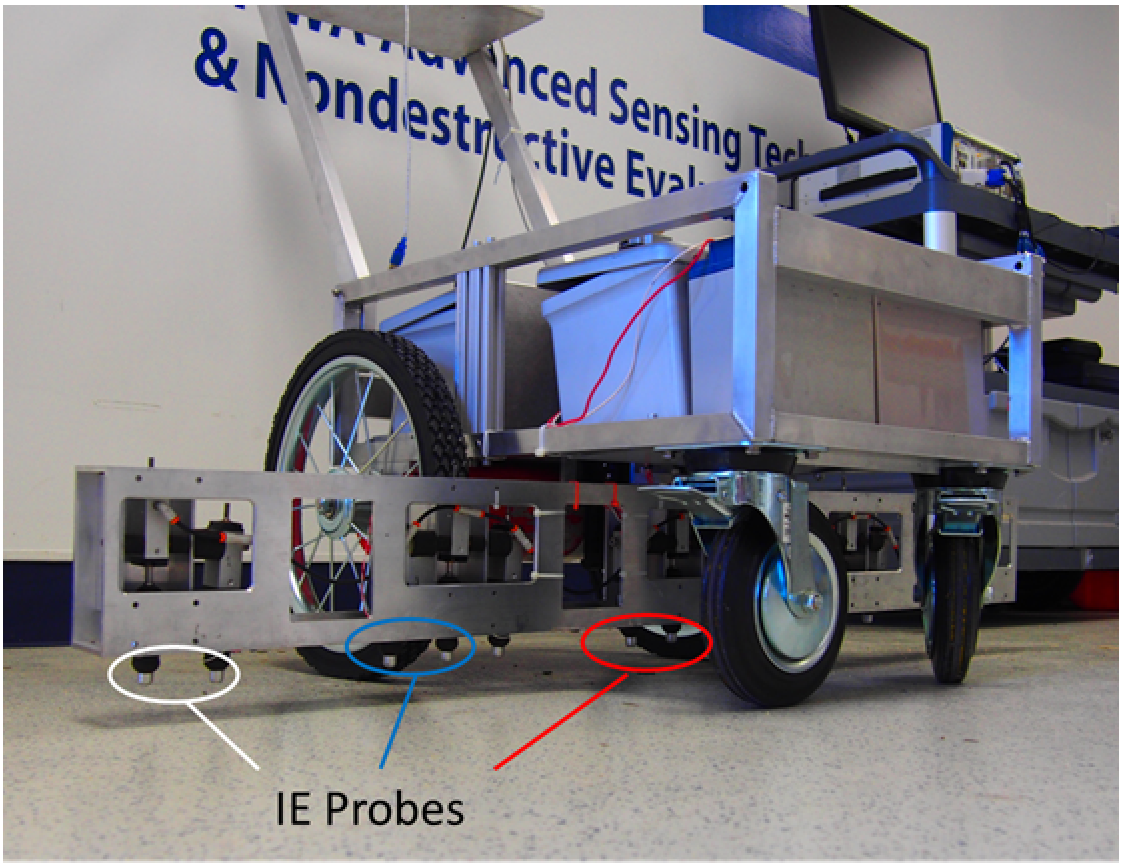
Primary applications of impact echo (IE) technology include the following:

- Detecting and characterizing defects, such as delamination and debonding in tnnel concrete lining and other members.[1]
- Measuring the thickness of slabs and walls.

Impact-echo has been successfully used as a means of non-destructive and time-effective evaluation of grouting quality in tunnel lining. [9]

Description

IE testing is a seismic or stress wave–based technology used to detect defects (primarily delamination) in concrete. The objective of an IE survey is to detect and characterize wave reflectors, or resonators, in a concrete structural element. IE devices can have multiple probes (figure 1) or a single probe (figure 2). Each probe consists of an impactor and receiver.



Source: FHWA.
Figure 1. Photo. Acoustic array with multiple IE probe pairs.

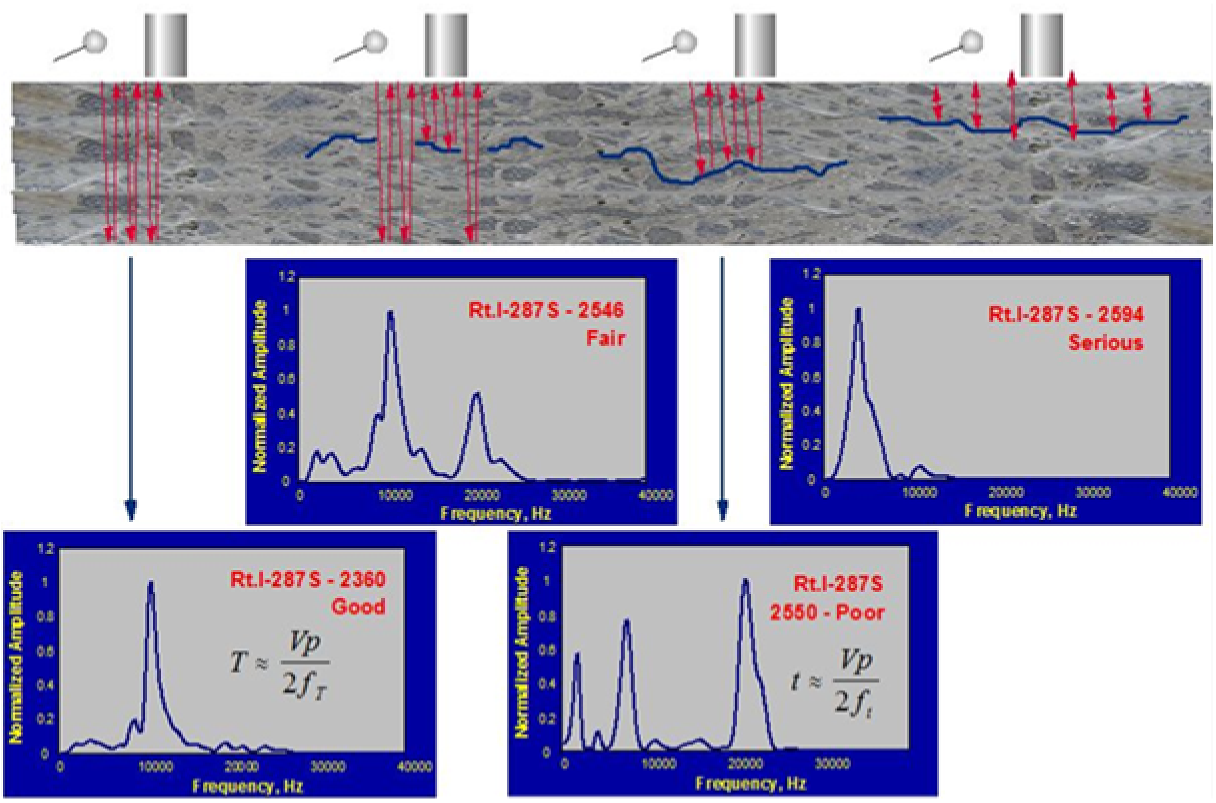
This photo shows an acoustic array system with multiple impact echo probes. The system is integrated with a mobile cart. The front wheels of the cart are smaller than the rear wheels. A metal beam reaches out between the front and rear wheels in the transverse direction below the cart frame.

Source: FHWA.
Figure 2. Photo. Manual IE testing using a single probe and a closeup of the probe.[2]

This photo shows a worker kneeling on a concrete road surface. His right hand is holding impact echo (IE) sensors against the concrete surface. His left hand is holding the data recorder. The sensors and recorder are connected by a cable. An inset on the right is a closeup view of the IE sensors. The locations of the impactor and receiver are indicated with arrows.

Physical Principle

IE testing is conducted using an impactor and sensor. The impact generates waves that propagate within the solid material. Waves are reflected by internal defects (differences in acoustic impedance) or boundaries. The reflected waves, or echoes, return to the surface and are measured by the receiver. The multiple reflected waves monitored by the sensor manifest as resonance conditions in frequency domain analyses. Defects, such as delaminations and big voids, can be detected by changes in the resonant frequency compared to intact areas. The principle of IE testing is illustrated in figure 3. The resonant frequency of areas with deep delaminations is higher than that of the sound areas (thickness mode). The resonant frequency of areas with large shallow delaminations is lower than that of the sound areas owing to excitation of the flexural mode.



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T = concrete slab thickness; V_p = pressure wave velocity; f_T = resonance frequency of the thickness mode;
f_t = resonance frequency of the delamination.
Figure 3. Illustration. Physical principle of IE.[3]

The illustration is a two-dimensional schematic of impact echo (IE) testing and typical spectrums for different levels of bridge deck delamination. The upper part of the figure shows a cross section side view of the IE test being performed at different locations on a concrete slab. A rectangular area represents the concrete slab. There are impact hammers and sensors at four locations on the slab surface. Arrows represent the propagation and reflection of the stress waves in the concrete after impacts. Roughly horizontal curves indicate the locations of delaminations in the concrete. The lower part of the figure contains four graphs showing corresponding spectrums obtained from the IE tests at the different locations. The x-axis of each graph represents frequency, ranging from 0 to 40,000 hertz. The y-axis of each graph represents normalized amplitude, ranging from 0 to 1.2. The first graph on the left has a high peak at approximately 10,000 hertz and is labeled "Good." The second graph has a high peak at approximately 10,000 hertz and a smaller peak at approximately 20,000 hertz and is labeled "Fair." The third graph has a high peak at approximately 20,000 hertz and two smaller peaks, one close to the origin and one at approximately 7,000 hertz, and is labeled "Poor." The fourth graph has a peak at approximately 4,000 hertz and is labeled "Serious."

Data Acquisition

A complete data collection procedure is provided in ASTM C1383-15, *Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method*.[4]

The structural surface to be surveyed should be cleaned of debris before IE testing. The survey should be conducted on the densest grid possible. The grid should be marked using washable paint or chalk.

The impactor of the IE system should be carefully selected to provide enough energy in the frequency range of interest. Some impactors are equipped with a sensor to measure the characteristics of the impact. Many IE systems use steel balls of different sizes as impact sources; the center and maximum frequencies are inversely proportional to the diameters of the balls.

Data Processing

The amplitude spectrum obtained from the fast Fourier transform analysis of the time-domain signal will show dominant peaks at certain frequencies, which can be interpreted to assess the slab thickness or potential delamination or debonding.

The thickness mode normally dominates the spectral response of a platelike structure that does not contain any near-surface defects.[5] The frequency of the fundamental thickness mode can be related to the thickness of the member (figure 4).

$$T = \beta \frac{C_p}{2 f_{IE}}$$

Figure 4. Equation. Calculation of thickness or depth.

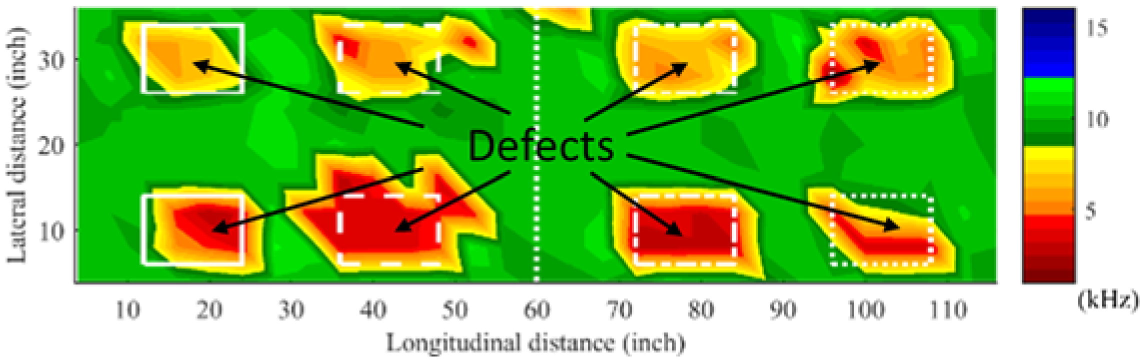
T equals the product of beta times the quotient of C subscript p divided by the product of 2 times f subscript IE.

- *Where*:
    - T = thickness or depth of a defect.
    - β = Correction factor.
    - C_p = Compressive-wave velocity of concrete.
    - f_{IE} = IE frequency.

Accuracy or uncertainty in thickness estimates from IE testing depends on a pooled error of the return-frequency measurement and P-wave velocity determination (figure 4). The typical uncertainty in thickness measurement is 5–10 percent. (See references 3, 4, 6, and 7.) Other factors that may impact uncertainty include the stiffness of the underlying layer, closeness to boundaries, and texture of the concrete surface.[4]

Data Interpretation

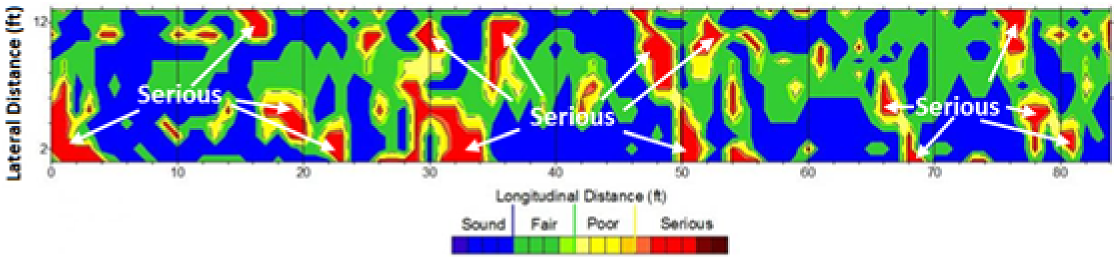
IE results are presented in various forms, some describing the position of reflectors, some interpreting the condition with respect to the state of delamination.[2] Figure 5 presents the dominant reflectors, or resonators, in terms of the spectral surface. The colors indicate different dominant frequencies identified in the response spectrum. Greens indicate normal thickness and no defects. Reds correspond to flexural oscillations of shallow delaminations.



Source: FHWA.
1 inch = 2.54 cm.
Figure 5. Contour map. IE data presented as frequency.

This contour map shows frequencies of a surveyed area. The x-axis represents longitudinal distance, ranging from 4 to 116 inches. The y-axis represents lateral distance, ranging from 4 to 36 inches. To the right of the graph is a color scale of frequency, ranging from 0 to 15 kilohertz. The majority of the map shows a dominant frequency around 10 kilohertz. Eight areas with low frequencies indicate defects in the concrete deck.

Results of IE tests often use different condition grades to indicate the progression of delamination development (figure 6). For example, fair and poor grades refer to incipient or progressed delamination, and serious grades correspond to either shallow or wide delamination.



1 ft = 0.305 m.
Figure 6. Contour map. Condition assessment with respect to delamination progression.[8]

This contour map shows delamination of a surveyed area. The x-axis represents longitudinal distance in feet, ranging from 0 to 84. The y-axis represents lateral distance numbered from 2 to 12 feet. A color scale at the bottom shows levels of delamination, ranging from sound to serious. The contour map contains irregular areas of different conditions. Most of the map shows sound and fair conditions. Large areas of serious condition are located at longitudinal distances of 0–4, 18–24, 28–34, 48–52, and 76–80 feet.

Advantages

Advantages of IE testing include the following:

- Early detection of delamination.
- Capable of detecting debonding between layers, such as concrete-type overlays.
- Fast data analysis with respect to delamination characterization.
- Unambiguous data interpretation.
- Insensitive to traffic-induced vibrations.
- Reliable and repeatable when conducted properly by an experienced operator.

Limitations

Limitations of IE testing include the following:

- Moderate to significant expertise and training required for equipment setup and data collection, processing, and interpretation.
- Slow data collection using traditional single-probe equipment; requires traffic control and lane closure.
- Dense test grid necessary to accurately define the boundaries of delaminated areas, adding to the test duration.
- Complex evaluation of conditions for overlaid roadways; cannot assess the condition of slabs in areas where the overlay is debonded.
- Consideration of geometrical and boundary effects needed, especially for structural elements, such as girders, columns, and caps.

References

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