MIRA

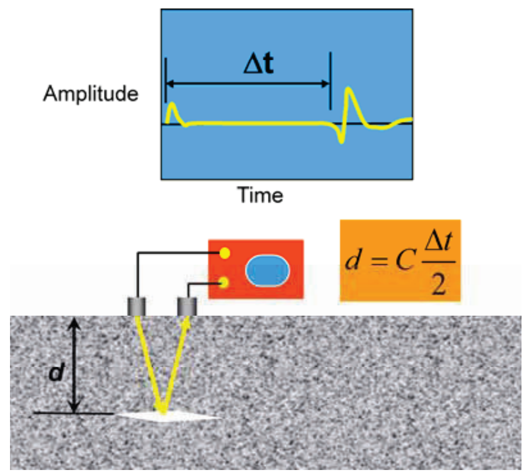
Purpose

The **MIRA Tomographer** is a state-of-the-art instrument for creating a three-dimensional (3-D) representation (tomogram) of internal defects that may be present in a concrete element. **MIRA** is based on the ultrasonic pitch-catch method and uses an antenna composed of an array of dry point contact (DPC) transducers, which emit shear waves into the concrete. The transducer array is under computer control and the recorded data are transferred wirelessly to a host computer in real time. The computer takes the raw data and creates a 3-D image of the reflecting interfaces within the element. **MIRA** has been used successfully for the following applications.

- Thickness measurement
- Detection of voids in grouted tendon ducts
- Detection of poor quality bond in overlays and repairs
- Detection of delaminations
- Detection of voids and honeycombing in concrete members

Principle

MIRA is based on the ultrasonic pulse-echo method using transmitting and receiving transducers in a "pitch-catch" configuration as shown on the right. One transducer sends out a stress-wave pulse and a second transducer receives the reflected pulse. The time from the start of the pulse until the arrival of the echo is measured. If the wave speed ***C*** is known, the depth of the reflecting interface can be calculated as shown (the equation assumes that the two transducers are close to each other).

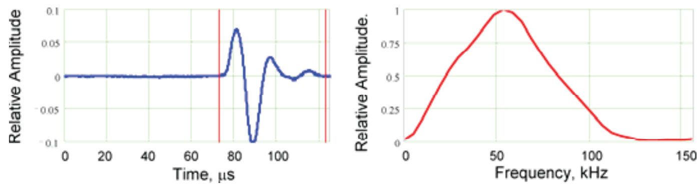


The key features that distinguish **MIRA** from other flaw detection devices include:

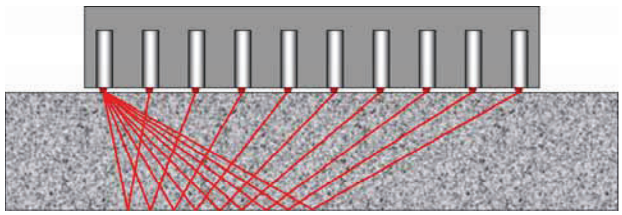
- The use of point transducers to introduce into the concrete pulses of **shear waves** with a nominal center frequency of 50 kHz
- The use of an array of point transducers to obtain rapidly 180 transit time measurements during each test
- The transducers are spring loaded to conform to an irregular surface and they do not require a coupling medium, that is, testing is done in the dry
- The transducer array (antenna) is connected wirelessly to the host computer, thereby eliminating the need for long cables
- The signals captured by the antenna are transferred automatically to the host computer, where the synthetic aperture focusing technique (SAFT) is used to reconstruct a 3-D model of the internal structure of the concrete
- The visualization software allows views of different slices of the reconstructed internal structure

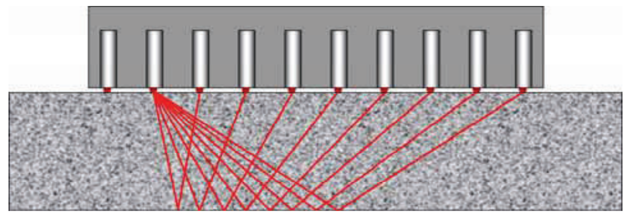
The following provides additional description of the principles involved in the **MIRA** system. The antenna is composed of a 4 by 10 array of point transducers and a control unit that operates the transducers. The transducers act as transmitters and receivers in a sequential mode. The transducers are heavily damped so that a short duration pulse is created. The first figure

to the right shows the typical shape of the received pulse after it has reflected from an air interface. Also shown is the amplitude spectrum of the pulse. It is seen that the nominal center frequency is about 50 kHz.

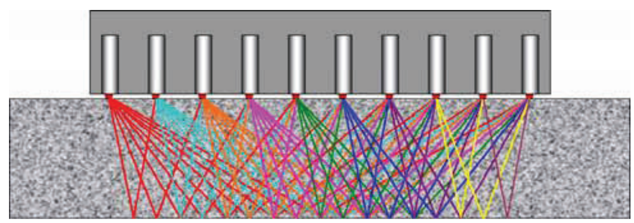


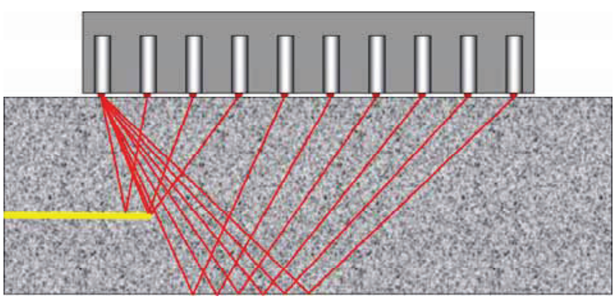
The operation of the antenna is described next. Basically, the control unit within the antenna excites one row of transducers and the other rows of transducers act as receivers. The left side figure below shows the first row of transducers acting as transmitters and the remaining rows of transducers acting as receivers. Then, as shown in the figure on the right, the next row of transducers is excited and the remaining rows to the right act as receivers. This process is repeated until each of the first nine rows of transducers has acted as transmitters.





The figure to the right shows the 45 ray paths that are involved for each of the four rows of transducers. It takes less than 3 seconds to complete data acquisition, data processing, and data transfer for a test at one antenna location. As will be discussed, the transit time for each reflected pulse is processed by the computer to create a 3-D model of the locations of the reflecting interfaces, which could be the opposite side of the member (back wall reflection), the location of reinforcing bars, and most importantly the location of internal concrete-air interfaces (such as voids, cracks, and delaminations).





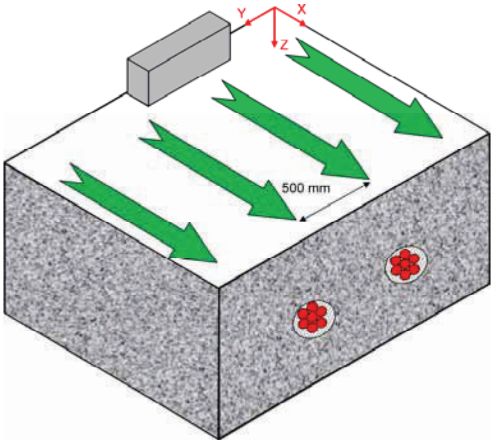
If there is a defect within the member in the form of a sufficiently large concrete-air interface, a portion of the stress pulse will be reflected by the defect; and the reflected pulse will arrive at the receiver sooner than reflections from the back wall. This is illustrated in the figure to the left. As discussed below, the signal processing software uses the arrival times of the reflected pulses to determine the location of the defect within the member.

Method of operation

There are four modes of operation of the **MIRA** system as follows:

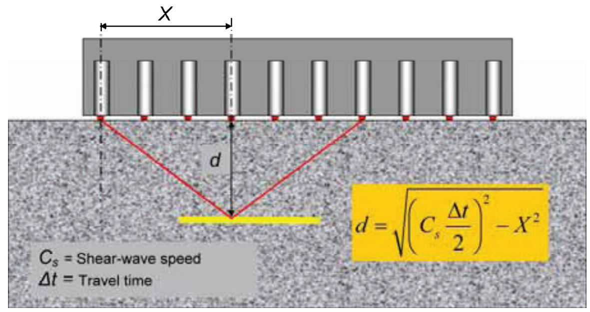
- CALIBRATION—This mode is used at the start of testing to determine the shear wave speed of the concrete. It is recommended that testing be done at eight or more positions to obtain a good estimate of average wave speed. The determined wave speed is representative of the concrete near the surface.
- EXPLORE—This mode is intended for preliminary testing at arbitrary locations on the surface of the test object. Ideally, preliminary tests should be done at locations where the internal conditions are known. This mode is used to check the settings of the instrument before beginning actual scans.
- SCAN—This mode is used to acquire the data that will be used to evaluate the test object. Data are stored automatically after completion of measurements at the antenna location. The method for conducting a scan is discussed below.

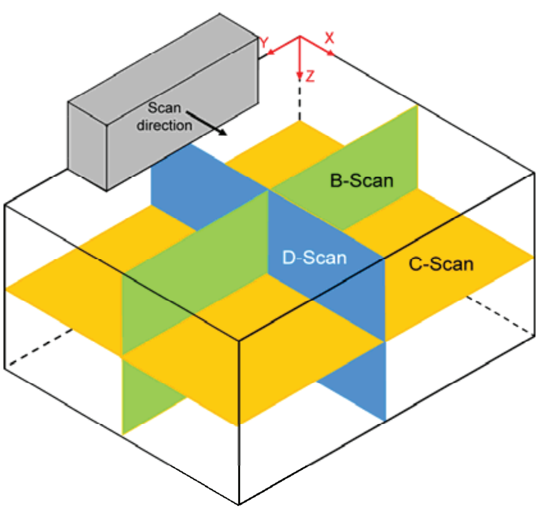
- REVIEW—This mode is for detailed study of the processed data acquired during the scan.



To carry out an inspection of the complete concrete member, the user lays out a series of scan lines 500 mm apart on the testing surface. The antenna is oriented perpendicular to the scan direction and data are recorded at predetermined steps along each scan line. The distance between successive antenna positions will depend on the nature of the defects to be detected, with closer spacings required for smaller defects. The testing layout is entered into the computer and that information is used during signal processing to establish the locations of the reflecting interfaces within the member.

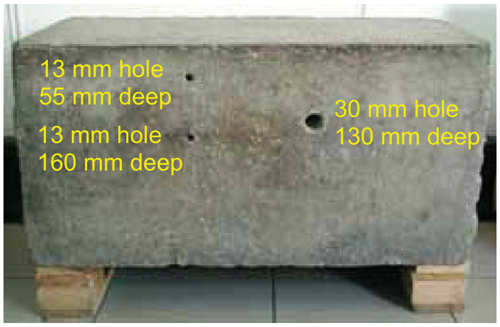
After data are acquired along all the scan lines, a signal processing technique called **synthetic aperture focusing** (SAFT) is used to reconstruct a 3-D tomographic image of the interior of the concrete member. In simple terms, the member is subdivided into small volume-elements (analogous to finite elements used for stress analysis). From the pulse arrival times and the known positions of the transmitter-receiver pairs, the depth of the reflecting interface can be established. Because of the inclined ray paths, the depth of the reflector is calculated using the formula for the relationship between the lengths of the sides of a right triangle (Pythagorean Theorem). In the formula shown to the right, C_s is the shear wave speed determined by **MIRA** during the initial calibration for the test object. If there is a large reflecting interface, reflections will be picked up by more than one receiver. This will allow reconstruction of the approximate extent of the reflecting interface.

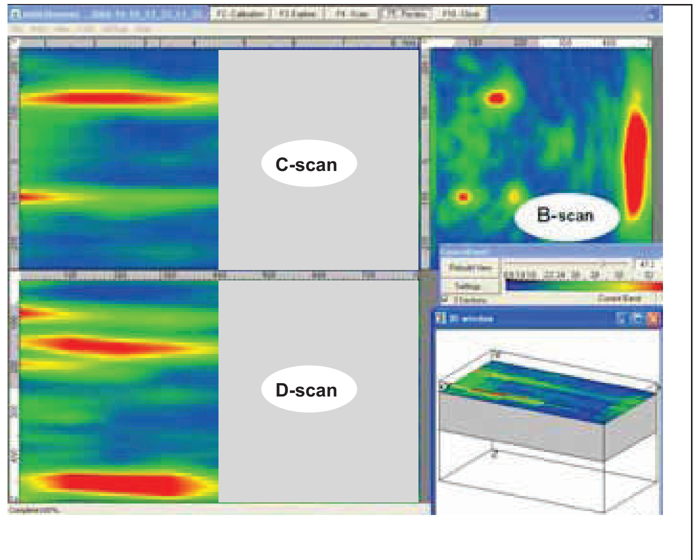




The reconstructed 3-D image is stored in the computer, and the user can look at a 3-D picture of the locations of all detected interfaces or the user can look at the projection of the interfaces on three orthogonal planes. The views on the three orthogonal planes have formal names. A **C-scan** shows the reflecting interfaces projected on a plane parallel to the test surface; that is, a C-scan is a "plan view" of the reflectors. A **B-scan** shows the reflectors projected on a plane perpendicular to the test surface and perpendicular to the scan direction; that is, it provides and "end view" of the reflectors. A **D-scan** shows the reflectors projected on a plane perpendicular to the test surface but parallel to the scan direction; that is, it provides an "elevation view" of the reflectors. The user can also look at specific "slices" through the member in each of the three directions by defining the Z-coordinate for a C-scan image, the X-coordinate for a B-scan image, and the Y-coordinate for a D-scan image.

The following is a simple test case to illustrate these different displays. The test object is a 0.43 m by 0.43 m by 0.8 m plain concrete block containing three holes as shown. The antenna was scanned along the center of the block parallel to the direction of the holes. The resulting cross-sectional views are shown. The red areas correspond to the locations of reflectors that produce high amplitude reflections. In the C-scan, we see a plan view of the holes. In the B-scan we see the end view of the block; the three holes are seen clearly and the large red zone is the bottom (back wall) of the block. In the D-scan, we see an elevation view of the holes and the bottom of the block. The views show the projections of all reflectors onto the three planes. The user can also look at the reflectors in specific slices.





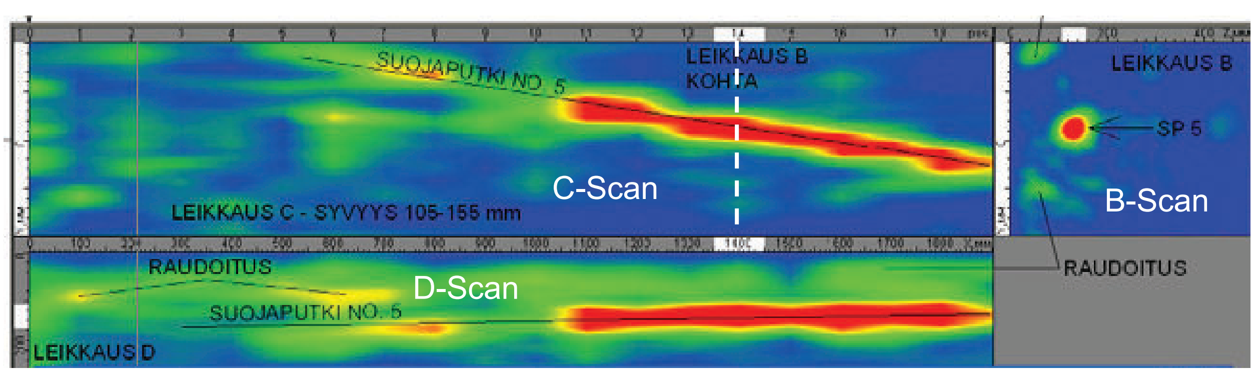
Testing Examples

Testing for voids in grouted cable ducts of bridge girders: **MIRA** was used to evaluate the conditions of prestressing ducts near the anchorage zones of a box-girder bridge. Before testing, the locations of the ducts were marked on the face of the web using information on the construction drawings (center photo below). One of the test records is shown below. The B-scan is at the cross section shown as a dashed line in the C-scan. The large amplitude signal at the location of duct indicated a high probability that the duct was not properly grouted. This was confirmed by drilling a core and carefully removing the duct to reveal the bare tendons. (Courtesy of Ramboll Finland Ltd.)

Scanning along web

View of web and drilled core

Condition of duct



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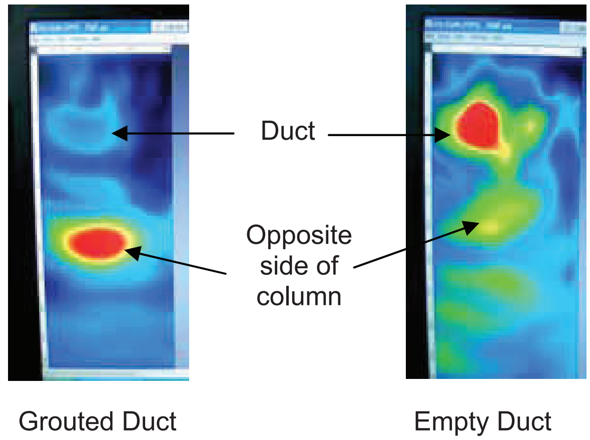
Testing for voids in grouted cable ducts in circular columns: Circular columns, 500 mm diameter, contained 80 mm steel ducts within the central cores. The ducts contained 25 mm bars that were supposed to have been surrounded with mortar grout. Single tests (Explore Mode) were made using **MIRA** and the results were displayed as a B-scan image. Voided ducts were easily identified and confirmed by drilling cores into the columns.

Single test being perfomed on column and condition observed after coring

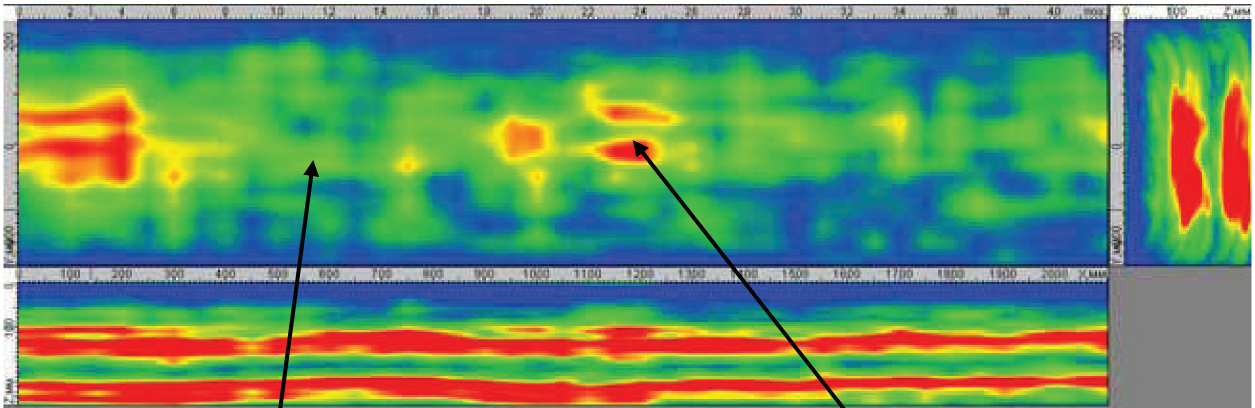


Examples of B-scans

Testing quality of bond: A steel box girder bridge was overlaid with 100 mm of fiber-reinforced concrete. The overlay included several layers of reinforcing bars that interfered with proper consolidation of the fiber-reinforced concrete below the bars. **MIRA** was used to evaluate the presence of voids at the interface with the steel deck. An example of the results from a scan line is shown below. Because of the shallow depth of the overlay, the B-scans and D-scans show the multiple reflections of the back wall of the overlay. The C-scan shows the locations of reflectors on a plane 90 mm from the top surface. The red regions represent possible presence of voids. Subsequent coring confirmed the **MIRA** results. Note that the green regions in the C-scan appear to be reflections from the reinforcing bars.

Scanning along overlay

Side view of overlay showing congestion of reinforcement



Solid Core

Core with voids below bars

MIRA Tomographer Specifications

- Dry point contact shear-wave transducers with ceramic wearing tip
- 50 kHz center frequency with 15 to 150 kHz operating frequency
- Transducers are spring loaded to conform to rough surfaces
- Phased array antenna containing 40 transducer in a 4 by 10 configuration; dimensions 435 × 235 × 146 mm; weight 4.5 kg
- Wireless communication (WLAN)
- Testing depth: 50 to 2500 mm
- Rechargeable batteries
- Time to process data at test location: not more than 3 s
- 3-D tomographic display
- Operating temperature -0 °C to 45 °C

MIRA Tomographer Ordering Numbers

Item	Order #
Laptop computer and case (not shown)	MIR-1001
Phased array antenna	MIR-1002
Wireless transmitter	MIR-1003
AC Adaptor	MIR-1004
Cables	MIR-1005
Software on CD-ROM	MIR-1006
User manual	MIR-1007
Wheeled carrying case	MIR-1008

Approximate dimensions of case and total mass of equipment
560 mm x 350 mm x 230 mm, 13 kg
22 in. x 14 in. x 9 in, 28 lbs

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