Abstract

The recent years have seen an increasing need of NDT diagnosis of concrete and natural stone constructions. Until recently the current investigation methods were limited to a very restricted area as well as to an investigation depth. Recent research programs have led to the development of an ultrasonic dry contact transducer enabling 3D tomography of solids such as stone and concrete. Shear waves spread easier and deeper into solids as opposed to the compression waves (P waves) used by Impact Echo. To investigate the tested object the tomographer uses an antenna formed by several bundled transducers, the multiple reflections of which are analysed by the so called “Synthetic Aperture Focusing Technique” which builds a 3D image as well as a 2D cross section of the given object. The obtained images, besides of the geometry of the object, show internal disturbances non visible at the outside surface such as voids, cracks, honeycombing… A state of the art software which includes wireless data-transmission generates an instant on site imaging. Following expose will discuss through 2 testing cases: one on natural stone monument and one on a concrete structure how such technology can bring answer in:

- The determination of the geometry of judge elements
- The assessment of the integrity of different material
- Detection of Delamination , plane of crystallization, graining veining in stone
- Early detection of spalling of cover layer due to corrosion

Key words: NDT diagnosis – shear waves – ultrasonic tomography – reinforced concrete – stone – heritage
1 MIRA TECHNOLOGY

1.1 BACKGROUND

The MIRA equipment is not based on any new test concept, rather a merging of well-known stress wave propagation principles and the advent and application of advanced hardware and analysis software packages.

Two major developments gave birth to the MIRA technology:

- Low frequency Dry Point Contact (DPC) ultrasonic transducers
- Synthetic Aperture Focused Technique (SAFT)

a) Low frequency Dry Point Contact (DPC) ultrasonic transducers

Research work performed at the Research Institute of MSI “Spectrum” in Moscow, Russia lead to the development of the low frequency dry point contact (DPC) ultrasonic transducers at the end of the 1980s. The DPC transducers primarily addressed the long-term problem of acoustic contact between the surface of the ultrasonic probe and the face of the concrete structure. Also there was improved sensitivity of the transducers by improving the directivity characteristics of the probes. In an essence, DPC transducers have been designed so that the size of the acoustic crystal in the piezoelectric element is several times smaller than the size of wavelength typically used to test concrete (40 mm or less). For example, if the wavelength of the propagating stress wave is nominally 40 mm, the contact zone between the transducer’s piezoelectric tip and the concrete surface is nominally between 1-2 mm for this transducer; thus the transducer tip becomes a point contact. In addition, a proprietary damper, made from a composite liquid which surrounds the entire free space of the piezoelectric element, has made it possible to provide higher oscillation attenuation with an increase in the ability to perceive the propagating wave. Finally, the directivity (longitudinal or transverse) of the propagating wave at the wearing tip of the transducer can be controlled by incorporating a dual piezoelectric element in the transducer casing. The longitudinal and transverse stimulation at the tip of the transducer is produced when both piezoelectric elements are either inphase or out-of-phase, respectively [5]. Figure 1 below shows a view of several DPC transducers in either a single or an array configuration.

![Figure 1- View of various DPC transducers in various configurations](image)
b) **Synthetic Aperture Focused Technique (SAFT)**

Assessment of internal flaws in concrete structures has been traditionally performed using point by point stress wave propagation methods; for example, test methods of UPV (using two transducers) or pulse-echo methods (using one transducer) are placed at a point to evaluate that point. In both cases, longitudinal waves are typically employed and analyzed to assess the condition of the test concrete at that point. With the constant improvement in computing power (faster computers), the ability to acquire fast data is most useful. More recently, however, data obtained from traditional ultrasonic stress wave propagation methods, combined with imaging reconstruction techniques have led to development of analysis software capable of imaging concrete in a manner similar to the medical radiology profession using magnetic resonance imaging (MRI) techniques. The MRI technique is, almost in real time.

Because of the heterogeneity nature of concrete, many combinations of data points are required to map out and accurately reconstruct an image depicts the internal condition. To overcome this obstacle, spatial averaging of a large number of single measurements per unit area under testing is typically performed using an array of low frequency, short pulse, dry point contact (DPC) transducers and a mathematical algorithm that uses a 3D synthetic aperture focusing technique (SAFT). SAFT is a signal processing tool used to improve the resolution of an ultrasonic image with focusing distortion.

### 1.2 TEST METHOD AND SYSTEM

The Ultrasonic Shear Wave Test Method, commercially known as **MIRA**, is a concrete flaw detection system capable of generating 3D tomographic images of concrete elements. The basic system consists a console with 40 transducers in an array of 10 rows each containing 4 Shear wave transducers. The transducers are spring-loaded, dry-point contact (DPC) piezoelectric sensors with a center frequency of 50 kHz. Each transducer is built with a wear-resistant ceramic tip, which allows testing even on very rough surfaces. Once the ultrasonic shear wave signal is emitted, the received signals are processed by the controlling console and then transferred to a laptop computer via Wi-Fi wireless technology for further analysis by proprietary software. A synthetic aperture focusing technique (SAFT) data processing method is then performed to generate the 3D images of the concrete element. The reconstructed images are displayed almost instantaneously (3 sec) on the computer screen as a plan view, cross-section, or isometric view. Images are generated from the signals received from all the combinations of PDC transducers (transmitting and receiving) in the antenna array. The **MIRA** system is commonly used in concrete, stone, and masonry structures to detect internal flaws such as delaminations, cracks, poorly consolidated or honeycombed concrete, as well as voids in grouted tendon ducts systems. Figure 2 below shows a view of the MIRA system.

![Figure 2- View of the Shear wave ultrasonic tomography MIRA System](image-url)
2 TESTING CASE 1: Heritage / Palace of justice of Brussels

This huge historic stone monument was erected in 1866. It is constituted of masonry, structural natural stones and esthetics stones.

2.1 Geometry of huge stones

The first test was to perform NDT evaluation of stone geometry / thickness. Figures 3 and 4 present the monument dome. The tested stones constituted the structure called “bleachers” the construction is detailed in figure 5.

Test zone 1

- Stone type: lime stone stone (comblanchian)
- Stone thicknesses are ranged between 30 cm and 200 cm.
- Calibration: shear wave speed was estimated at 3306m/s by Mira calibration

![Figure 3: Building dome](image)

![Figure 4: Stone Detail](image)

![Figure 5: Vertical cross section of tested bleachers.](image)
Figure 6 shows a single-cross sectional image of the test location shown by the black arrow in figure 5. Stone thickness was estimated about 1400mm.

Stone profile was indirectly drawn as indicated by the doted pink line in figure 7. Stone thickness variation is shown by the profile. Stone thickness is ranged between 300mm and 420mm. Thickness was confirmed by drilling and endoscopic investigations.
Test zone 2

Second test was performed on a big keystone compressed between to columns. The red arrow on figure 8 indicates the surface to be tested (keystone).

Figure 8: View of tested stones.

Figures 9 shows a single MIRA cross section which indicates shear waves reflection at 1450mm.

Figure 9: Transverse cross-section showing a MIRA shear wave reflection at about 1450mm.
2.2 Integrity of stones
Mira was used on different stones to evaluate their integrity:
- Homogeneity of the tested material
- Detection of delamination, plane of crystallization, graining veining, stylolite

a) Homogeneity
Figures 6, 7, 9 indicate no or very few reflections between the tested surface and the back wall, even at a high contrast level in 3D imaging. So we can conclude that the tested material is rather homogenous.

b) Heterogeneity/delamination/etc
Figure 10 gives the investigation of the column as indicated in figure 8 by the green arrow.

This cross section indicates a strong MIRA shear waves reflection at 500mm which represent the column thickness.

The other weaker reflections detected at 100mm and 200mm correspond to the depth of 2 stylolites, this was confirmed by core inspection.
2.3 Early detection of spalling of cover layer
Facing stones have been experienced from suffering of spalling induced by corrosion of steel members. MIRA was used to evaluate these spallings at early age and to draw the stone profile. Figures 11 show a view of the stones.

- Stone type: white lime stone (Tercé)
- Stone thickness: expected between 30cm to 60cm
- Calibration: shear wave speed was estimated at 1936m/s by Mira calibration.

Figure 11: View of facing stones.

Figure 12 show a transverse cross section of the tested facing stones. This figures indicates:

- Spalling at 90mm deep (see figures 13 and 14)
- Two different backwall reflections at 250mm and 500mm
This has been validated by break-ups and core samples.

The facing stone masonry profile could be drawn as indicated by the doted pink lines on figure 12.
Figure 12: Longitudinal cross-section view showing shear waves reflections (at 250mm and 500mm), spalling and stone profile.

Figure 10 and 11 show 2 examples of spalling due to corrosion of a steel member.

Figure 13: Spalling example n°1.  
Figure 14: Spalling example n°2.
3 TESTING CASE 2: Concrete sandwich walls of a waterbasin in Netherlands
These waterbasin walls in Netherlands were constructed in 2008. The walls of the basin are sandwich walls described as following:

- 60 mm of prefabricated reinforced concrete. (part 1)
- 120 or 180 mm of poured concrete (part 2)
- 60 mm of prefabricated reinforced concrete (part 3)

Total thickness of outer walls is 300mm
Total thickness of separating walls is 240mm

The correct structural behaviour of the wall is function of the bonding the three parts of the wall. These walls have been experienced for suffering of cracking and leakaging. Based on this the bonding between the parts becomes suspicious.

MIRA test method was used to performed field studies to evaluate adhesion between precast concrete walls and poured concrete. MIRA tests were performed at 28 locations.

Figure 15 and 16 show the waterbasin. Figure 17 describes a cross section of the outer wall.

Figure 15: View of waterbasin  
Figure 16: Cracks and leakages.

Figure 17: Outer wall cross section.
Figure 18 shows a unique backwall reflection at 240mm. This separating wall is solid. No debonding occurred within the cross section.

Figure 18: Longitudinal cross section of a separating wall showing strong Mira shear waves reflection at 240mm.

Figure 19 shows:
Backwall reflections at 240mm: no debonding from 0 to 1300mm and from 1650mm to 1800mm
Reflection at 180mm: debonding between part 2 and part 3 of the wall.

Figure 19: Longitudinal cross section of a separating wall showing multiple Mira shear waves reflections.

Figure 20: Single transverse cross section of a separating wall showing a backwall reflection at 240mm.
Figure 21: Validation core corresponding at a solid answer as shown in figure 20.

Figure 22 describes a surprising strong reflection (strange pattern) corresponding to a delamination at the interface between inner prefabricated element and poured in concrete.

Figure 22: Single transverse cross section of a separating wall showing strong Mira shear waves reflections near the surface (at about 50-60mm).

Figure 23: Bore hole showing a delamination at 6cm deep. Validation of figure 22.

**Conclusion:**
The test campaign on this waterbasin was totally successful and very fast. MIRA software allows quick analysis of longitudinal cross section at large scale even with a fine scan step (about 10mm). The analysis has been directly performed on site and all validation cores matched the MIRA results.
4 GENERAL CONCLUSIONS

MIRA technology is a new technique still in development and very promising. It allows on site quick assessment on material integrity. 3D image technique makes the results outmost convenient to analyze.

As already experienced on concrete reinforced structures for voids location, delamination, poorly consolidated zones, MIRA system is also efficient to analyze natural stones structures. Our last experiences demonstrate that this user-friendly technology could be used to analyze larger depths, more than 1.50m, maybe 2.00m. Furthermore, it allows multiple defects at different depths.

This technique has been successfully experienced for cable duct detection and their grouting defect evaluation. This subject need still further evaluation and in particular for deep multiple cables.

As every new technique, MIRA needs improvement and is suffering from a lack of experiences return. The capability and the limitation of the system are still not defined yet. New improvements in software interface and waves analysis are expected in the future. As end-users and developers are working on the same basis, all these expectations could be met relatively quickly and the test standardization could start.

REFERENCES

[4] A.A. Samokrutov, V.N. Kozlov, V.G. Shevaldykin, Ultrasonic Examination of Concrete Structures,