

PAPER • OPEN ACCESS

Experience of using the ultrasonic low-frequency tomograph for inspection of reinforced concrete structures

To cite this article: M S Kuznetsov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **481** 012047

View the [article online](#) for updates and enhancements.

Experience of using the ultrasonic low-frequency tomograph for inspection of reinforced concrete structures

M S Kuznetsov¹, O V Maltseva,² A S Noskov,³ A S Kuznetsov⁴

¹Department of Engineering, Nizhny Tagil technological Institute (branch) Ural Federal University, Russia

²Nondestructive Testing Laboratory, LLC "Proyektsia", Russia

³Department of Hydraulics, Ural Federal University, Russia

⁴LLC "Proyektsia", Russia

Abstract. The article shows the hands-on examples of using the ultrasonic low-frequency tomograph type A1040MIRA which has been developed and created by the Research and Manufacturing company "Acoustic Control Systems" (LLC "ACS") for detection of internal flaws in concrete and reinforced concrete structures. The device is shown to be used for detecting the bodies of unrammed concrete (discontinuities of concrete) in the framework and measuring of its residual load-bearing capacity. Furthermore, the tomograph has been found useful to evaluate consolidation of concrete in hydraulic facilities. A1040MIRA resolves the issues of measuring the thickness of a concrete structure from either both sides if readily accessible or from just one side if the access is limited, or those of measuring a layer thickness in a sandwich structure. The article shows that for reliable "reading" of the images produced by the instrument the preliminary study of the reinforcement principle of a structure, of its geometry, the configuration of the reinforcements and the working environment is required.

1. Introduction

The detection of flaws both explicit and hidden is one of the main objectives during inspection of the reinforced concrete structures. They provide maximum data on the technical condition of the structure, its bearing capacity and durability.

The evidence from practice shows that the lack of high production standards, unskilled labor used for installation, a substandard quality control system or a general lack of any quality control system can produce significant flaws in the concrete body of both the load-bearing and the walling members during their casting.

The flaws can arise from disintegration of a concrete mix where inadequate ingredients are used, the mix is ill-proportioned or the batching time is failed, or the mix drop height is incorrect. Defects in the structure of concrete occur where the concrete mix is insufficiently consolidated or completely loose or where the construction joints are failed.

During operation of buildings and facilities made of the reinforced concrete structures the additional flaws may be triggered by corrosion of rebars, the effect of freeze-thaw temperatures, water proofing failures and other.



All these flaws show as cavities, cracks both on the surface of a concrete structure, and inside its body. And while the surface defects are visible and detected by the construction inspectors, the internal defects are difficult to reveal.

Defects of the structure directly affect the density and uniformity of concrete, and, consequently, its strength and durability.

At the end of the day the challenge is to identify the severity level of a flaw revealed in a concrete or reinforced concrete structure. Here are some of those:

- what are the size and the area of the unconsolidated portion of concrete in the section of the load bearing structure;
- how dense is the concrete in the hydraulic facilities;
- does the concrete structure comply with the design criteria in the case of a one-sided access with no access for hole boring.

2. Method of inspection of reinforced concrete structures

The above challenges can be resolved by using the ultrasonic low-frequency tomograph type A1040MIRA which has been developed and manufactured by the Research and Manufacturing company "Acoustic Control Systems" (LLC "ACS"). The device is intended for inspection of monolithic concrete and reinforced concrete structures in order to detect voids, ducts, rebars, foreign inclusions, segregations, cracks and other cavities, both unfilled and filled with liquid or solid material which differs from surrounding concrete in its physical and mechanical properties.

The device can scan concrete to the depth of up to 2,500 mm and up to 800 mm in case of reinforced concrete. Thickness of the structure can be measured in the range between 50 and 600 mm.

Multiple data from the inspected area is collected by a matrix antenna array of 48 low-frequency broadband transverse wave transducers with dry point movable contacts. The total area of the antenna array is 380x140 mm. The inspected structure and its sections are visualized via special software which uses a three-dimensional Cartesian coordinate system which is referenced to the position of the device on the structure, as in Figure 1.

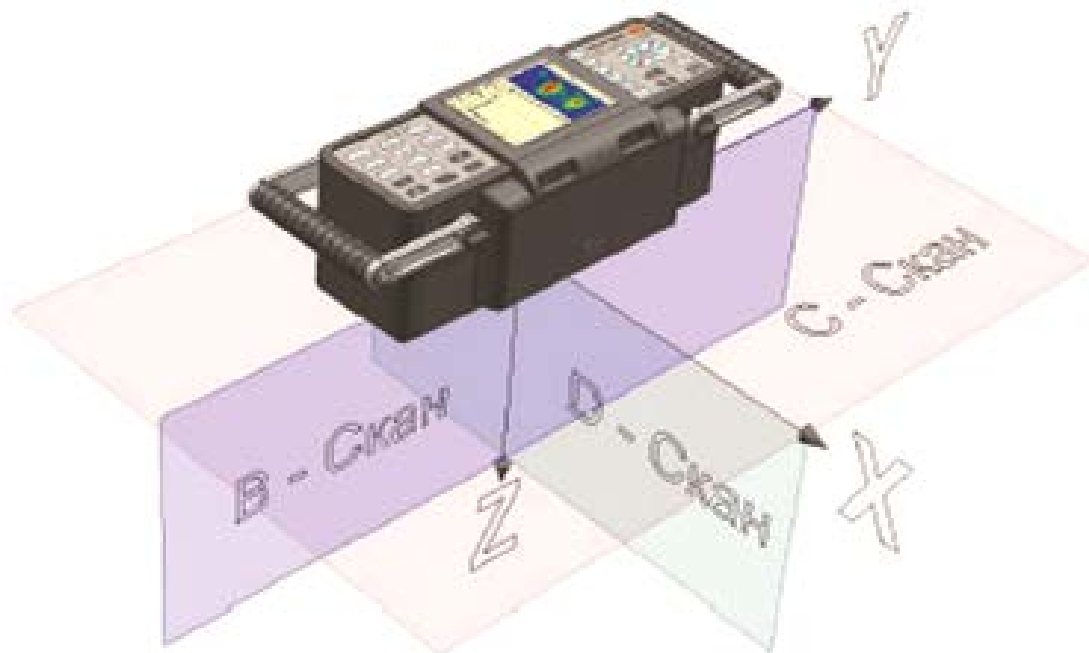


Figure 1. System of coordinates of the device position on the structure and the scan echo signals.

Signals from the antennas are processed by the built-in computer, displayed on a monitor and stored in the device's memory. The software offers reading of data and their displaying as images. Visual images of the sectional views of the inspected structure are produced where each point of the scanned visualized volume is color coded based upon its echoing property.

The device enables the UT inspection of the area in different modes. The "Overview" mode is intended for customizing the parameters of the device for the object under inspection: obtaining the image sharpness and reflecting the corresponding thickness of the structure, setting the average ultrasonic waves propagation velocity for fast search for defective areas.

The so-called B-Scan is produced on the screen of the device, which shows the section of the structure tested in the direction normal to the antenna surface (see Figure 1).

The "Map" mode is used for the areas where the flaws or their indications are detected. An array with certain spacing is applied to the surface of the tested area. The device collects the body of scans produced by a step-by-step motion of the antenna array. Eventually either a three-dimensional image or those of the scans of three planes, so-called image maps, are displayed via the IdealView software. Furthermore, you can view all the images of the tested area of the structure by moving the secant planes of the area.

See [1, 2, 3] for the real working principles of the tomograph as well as the process of imaging with various noises and images. The capabilities of the device in detecting large defects in concrete are shown, both in specially constructed trial blocks and in structures at existing facilities. Before starting to work with device you are recommended to acquire the experience of scanning the concrete trial blocks which contains various artificial defects. See the examples of the structure thickness measurements where the one-sided access is available. Furthermore, [2] shows various methods of non-destructive testing and the instruments for solving these problems. The conclusion is that the tomograph is the most informatory device for inspection of the reinforced concrete structures.

"Proektsiya" LLC has been using the ultrasonic low-frequency tomograph type A1040MIRA to measure the density of the structure (so-called continuity) of concrete in the erected reinforced concrete structures at various facilities inclusive of those hazardous and sophisticated.

A series of inspections have also been carried out to reveal internal defects and unconsolidated areas of concrete in building structures. Thicknesses of the concrete members such as the walls of tanks, tunnels and others have been measured many times.

When we just started to use the device we hoped to see the commonly understandable images similar to those we expect to see at the drawings, i.e. the structures with dimensions, with the rebar locations, with internal defects (cavities). And in three dimensions to top it off.

However, the very first test showed blurry "spot" patterns. We could hardly make out the images which belonged to the rebars and those of the concrete flaws and whether they were in there altogether since the designed locations of the rebars in the structure were unknown to us. Upon that we made sure to study the structure design first and that of the reinforcement before starting to use the device. Then the images became friendlier.

Please find below several examples. Scanning of the 250-mm floor. The reinforcement diagram and the antenna array application area are shown in Figure 2 below. The flooring is reinforced by two meshes, the bottom and the top, made of dia. 12-mm bars arranged in two orthogonally related directions with a 200-mm spacing. The protective mesh concrete layer thickness is 50 mm on both sides.

Figure 3 shows a B-scan of the flooring where some images are visible due to the difference in their color. The position of the images in the section of the structure can be judged by from the axes of the coordinates, X and Z . The horizontal axis X origin is at the center of the antenna array and rubs along the longitudinal side of the device. The vertical axis Z origin is on the surface of the structure to which the device is applied, and shows the location of the images along the thickness of the structure. The coordinates of the image of interest on the B-scan are identified by moving the horizontal and vertical cursor on the screen. Further, the A-scan on the instrument's screen shows a graph of the images echoing property. The images which are lined up horizontally along the X axis, at a distance of

about 50 mm from the structure's surface where the device is located, show the bottom reinforcement mesh of the flooring. The top reinforcement mesh, judging by the scan, is located about 150 mm from the floor surface. The ultrasonic waves are echoed from the bottom surface of the flooring at the interface between concrete and air (by reference to the device location), which is seen on the scan as a large image with Z coordinates equal to 250 mm, or the so-called backwall image. Its location confirms the thickness of the flooring being tested. The B-scan shows no images other than those which belong to the design elements. Thus, there are no structural flaws (discontinuities) of concrete on the scanned area of the floor structure detected.

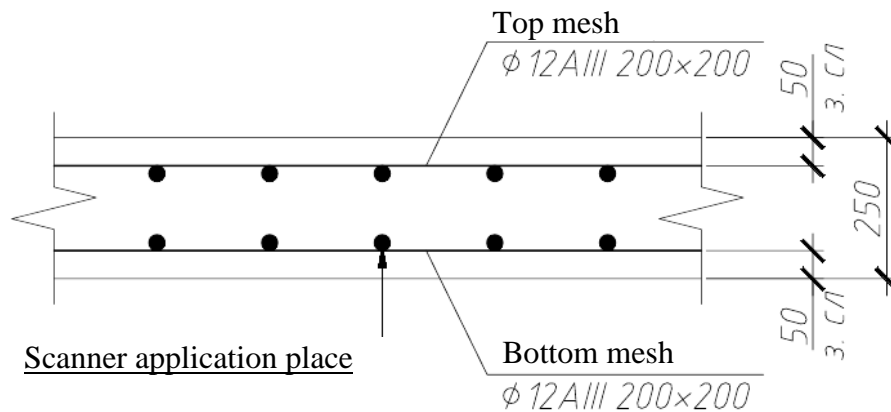


Figure 2. The floor reinforcement pattern and the device application place.

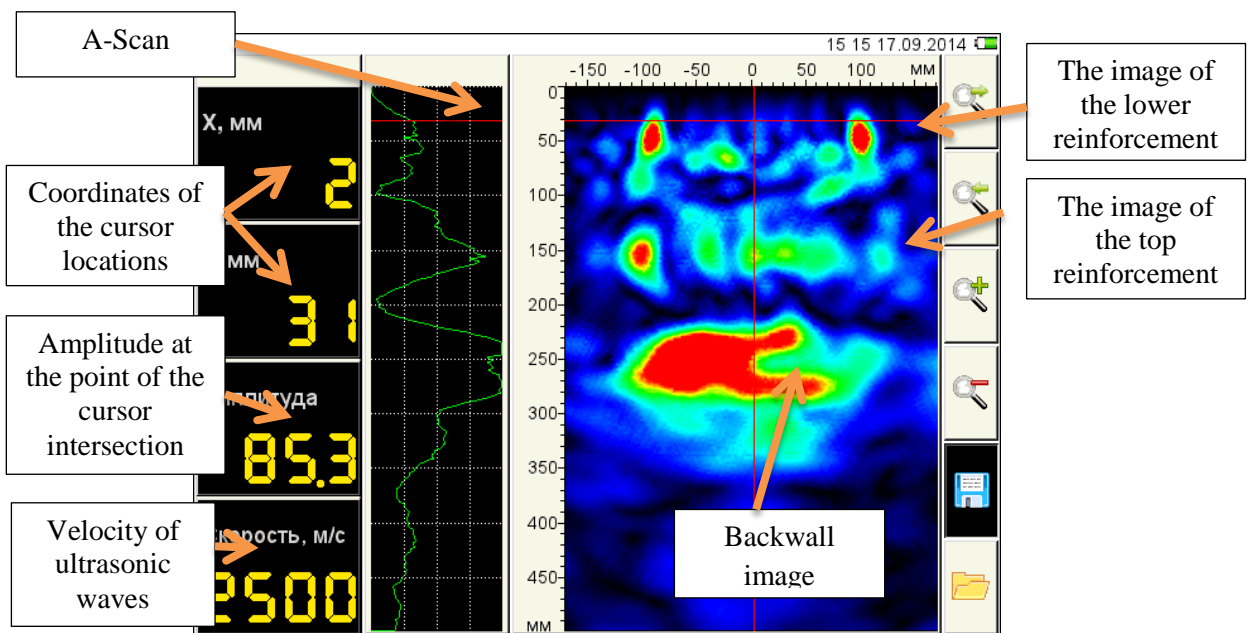


Figure 3. Scan of the 250-mm flooring with images of the nearby and distant rebars and the backwall image.

The scan shows no extraneous images, thus, there are no defects in the structure (discontinuities) of the concrete.

The scans below are made on the 300-mm wall of a tank. The wall reinforcement pattern and the tomograph's antenna array application diagram are shown at Fig. 4. The wall is reinforced by two meshes interconnected by transverse frames.

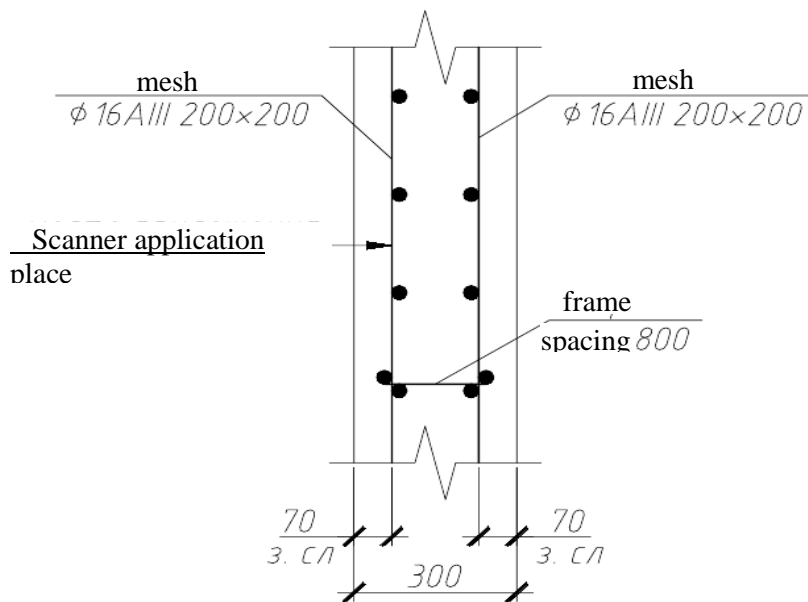


Figure 4. The tank wall reinforcement pattern and the tomograph's antenna array application diagram.

The tomography at Figure 5 clearly shows the images of two layers of reinforcement (two meshes) which are located at about 70 mm from the surfaces of the structure (protective layer of concrete). The backwall image of the structure is clearly visible at a distance of 300 mm. The interface between concrete and air shows the thickness of the structure. The scan shows no extraneous images, no structural flaws (discontinuities) of concrete in this area.

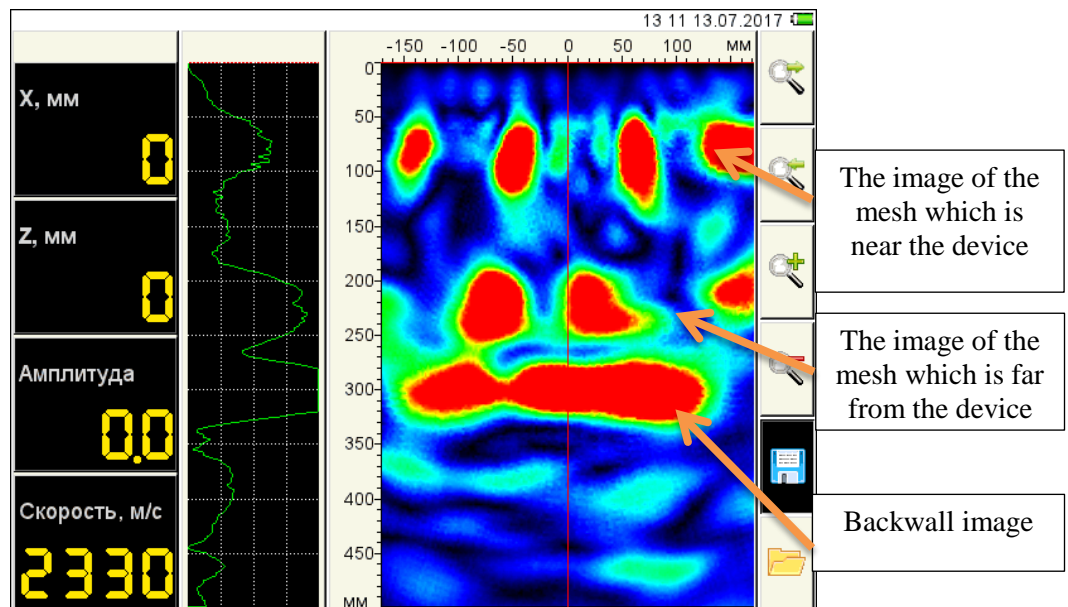


Figure 5. The tank wall scan with the reinforcement images and the backwall image.

A scan (Figure 6) with additional images lined up between two tiers of the mesh images was made at another area of the same tank wall. The transverse frame which connects the reinforcement meshes is obviously located here. A small number of additional images are seen at the location of the

reinforcement. Obviously, the concrete is not dense enough in the area of the reinforcing cage. Therefore, the ultrasound velocity goes down.

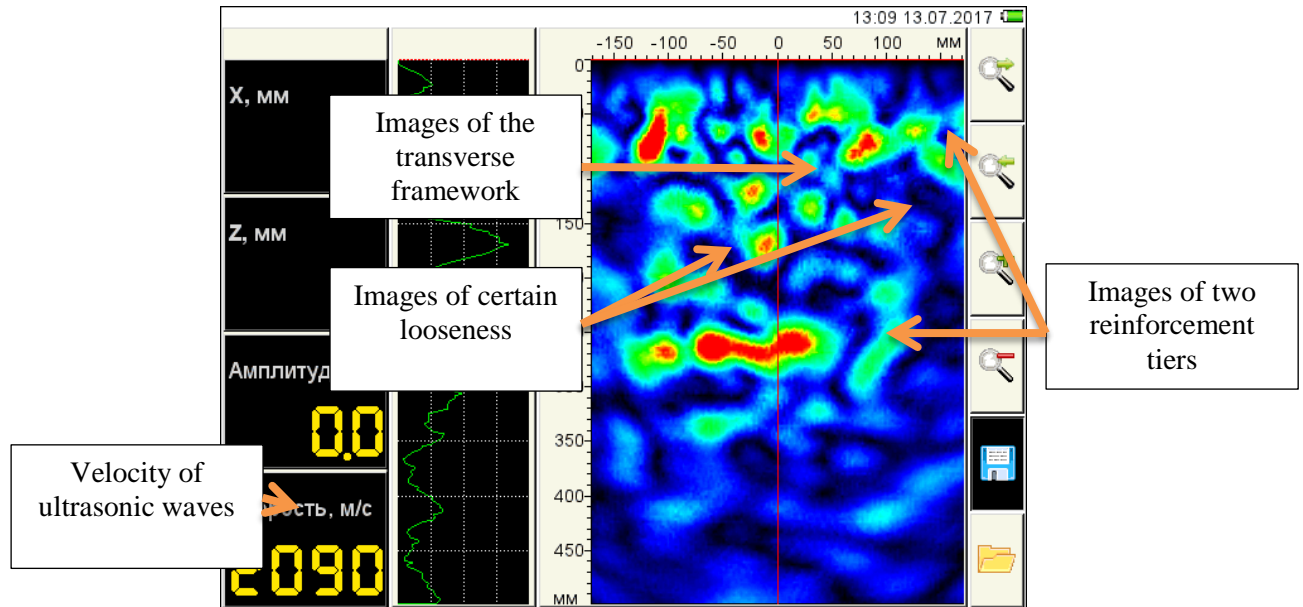


Figure 6. The tank wall scan with images of the transverse reinforcing cage between the near and distant meshes and the unexpected images of some loose concrete.

The same tank wall was further scanned in the loose concrete areas (Figure 7). The ultrasonic waves velocity here is lower than that in dense concrete. A large number of foreign images indicates a lack of consolidation of concrete to the depth equal to 250 mm of the structure thickness. The waves stop short of the backwall of the structure and are echoed from the indications. Consequently, the backwall image is not seen on the scan.

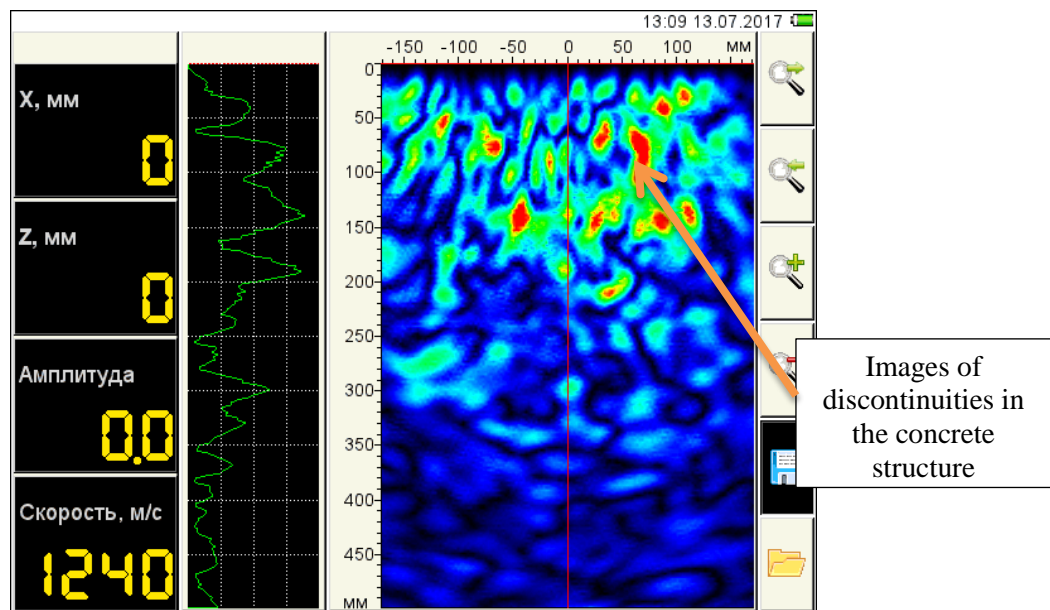


Figure 7. The scan of tank wall in the area of loose concrete.

Furthermore, the tomographic image mapping was performed for these areas of the tanks with loose concrete. The scans of the structure body in this area were collected for mapping by moving the device in 100-mm increments along the grid which has been preliminary made on the surface of the structure.

See Figure 8 for a screenshot of the plane scans of the tested area. The B-scan shows extra images undesigned between two reinforcement tiers, which may prove to be foreign matter or most probably cavities resulted from loose concrete. The C- and D-scans are shown along the secant planes of the body at the place where they run through the foreign images.

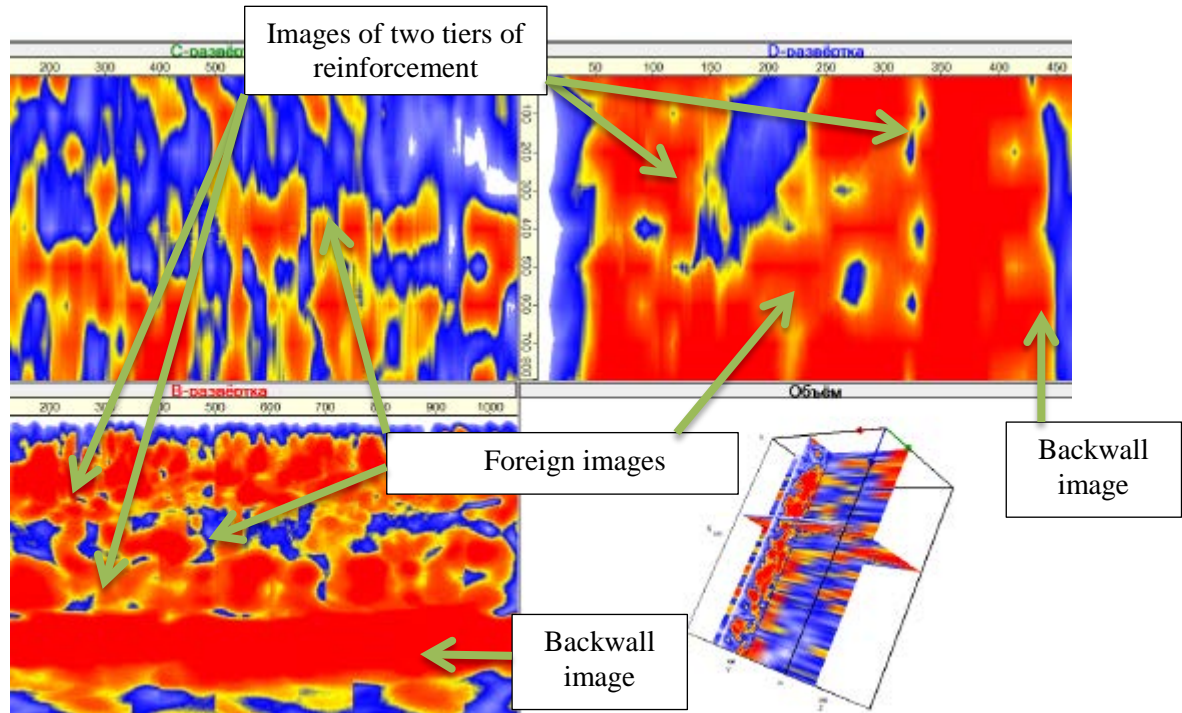


Figure 8. Screenshot of the plane scans at the tank wall area with echoes from the two tiers of reinforcement, the backwall and foreign images.

Built-in columns seen as wall piers were scanned in the same tank

Here the wall thickness is increased to 400 mm. The scan performed on a dense area of concrete is shown in Figure 9. It clearly shows the images of the reinforcement and the backwall image of the structure at a distance of 400 mm.

One of the piers showed a centerline defect seen as a long narrow cavity running deep into the body of the structure. At this area, the scan shown at Figure 10 has been made. As can be seen from the scan, the cavity runs deep inside and transforms into a large cavern which opens onto the opposite surface of the structure. The defect echoes the waves, the backwall image is missing.

From the scans it is clear that the images of the defects and those of the reinforcement look identical. A huge amount of scans of the structure has been collected to identify the typical patterns with the images of the reinforcement elements at their designed positions to understand the location of the images and detect their flaws. Any deviations, foreign images located in places where they are not expected to be, required interpretation and could be indications of the concrete structure discontinuities.

Operation of A1040MIRA requires a wide experience of UT scanning of various items. To acquire the experience the device developers and some scientific works recommend manufacturing and scanning of the trial concrete blocks with artificial reflectors (simulated flaws). However, this is labor-intensive and does not offer an accurate simulation of the defects encountered.

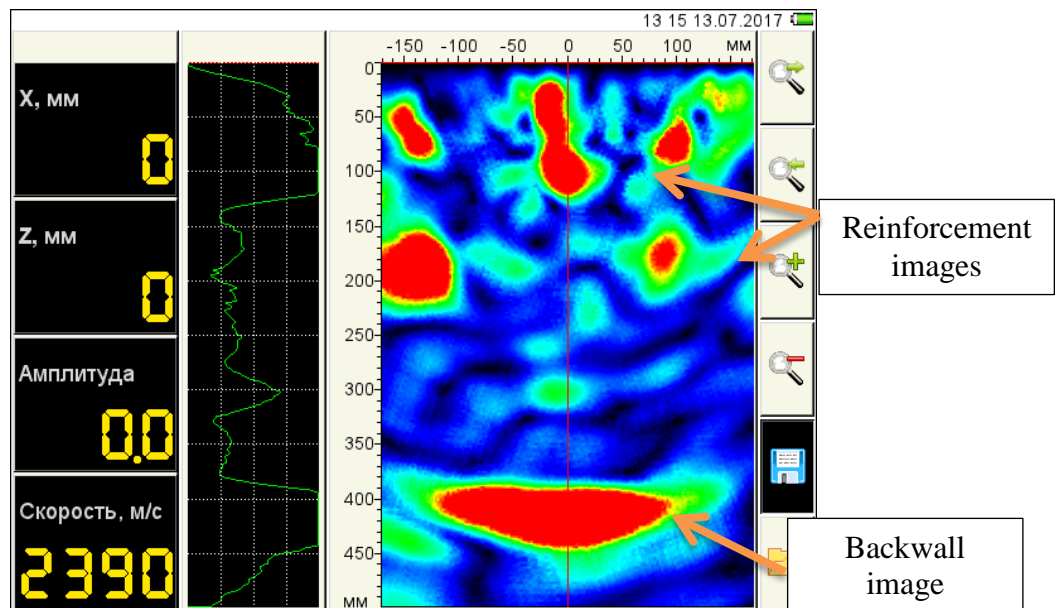


Figure 9. The tank wall scan at the pier location.

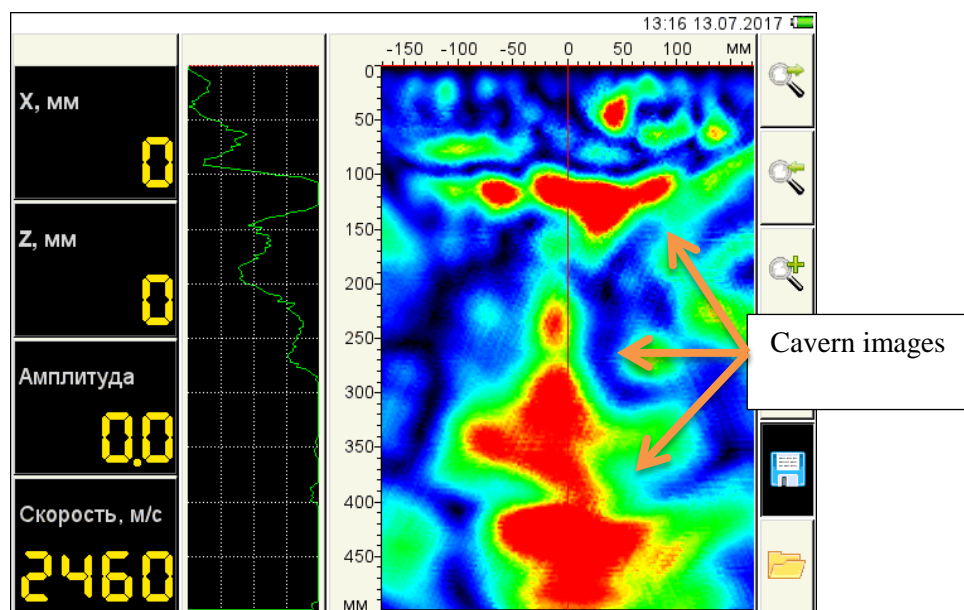


Figure 10. The tank wall image at the pier location with a large cavern image in the center of the pier.

To acquire the experience a 600-mm column was scanned in situ with a conduit in the center (figure 11). The scan clearly shows the images of the near reinforcement and those of the embedded part. The backwall image is missing since the waves won't go beyond the conduit and are reflected by it.

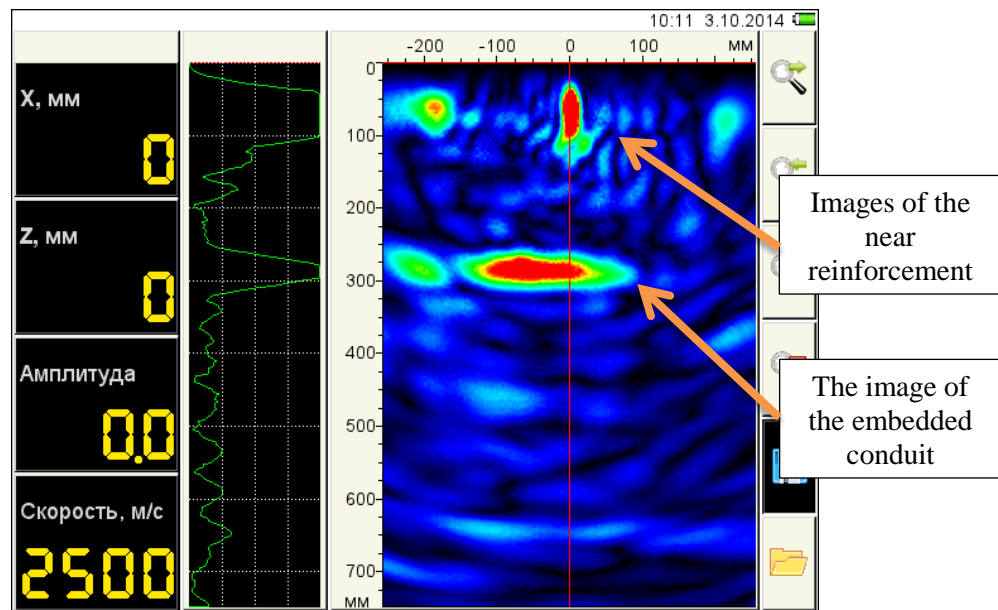


Figure 11. Scanning of the column with the embedded pipe at a distance of 300 mm from the surface.

Figure 12 shows a scan of the same column at the conduit free area. The images of the near reinforcement and the backwall image of the structure are clearly visible at a distance of 600 mm which is the section size of the column.

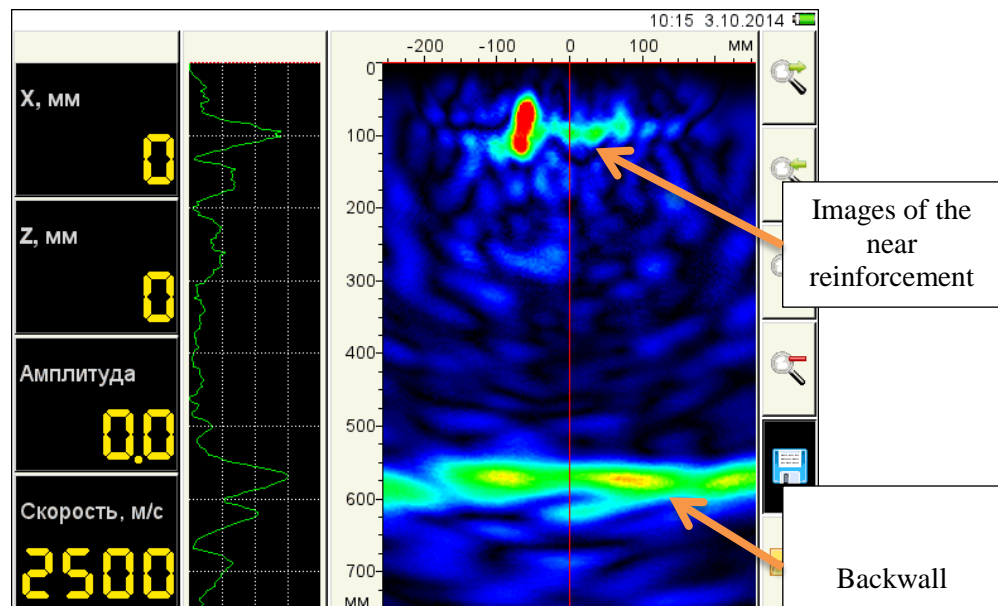


Figure 12. The column scan at the conduit free area.

Identification of defects in the body of concrete and reinforced concrete structures of buildings and constructions by A1040MIRA tomograph has prevented emergencies at hazardous facilities. Decisions on the further operation of defective structures were based on the size and location of the defects:

- “heal” the structure with special repair mixes as deep as the defect runs;
- reinforce structures with metal yokes and carbon reinforcement systems from outside;
- dismantle the structure.

3. Conclusions

Before A1040MIRA scanning of structures it is necessary to know the reinforcement principle of a structure, its geometry, the configuration of the reinforcements and the working environment. Information on the concrete placement procedure, construction joints, undesigned concrete placement interruptions, consolidation methods, the mix drop height, environment effecting the structure will explain the unexpected images on the scans. Just the reliable tomographic images will assess the effect of internal defects on the structure performance.

A1040MIRA tomograph is helpful in detecting the body of loose concrete (discontinuities in concrete) in the load bearing structure and identifying its residual bearing capacity.

A1040MIRA helped assess the degree of concrete consolidation in the structures of hydraulic facilities.

A1040MIRA helped resolve the issues of measuring the thickness of a concrete structure from either both sides if readily accessible and from just one side if the access is limited, or those of measuring a layer thickness in a sandwich structure.

References

- [1] Samokrutov A 2012 Conclusion on the "A1040 MIRA" tomograph ultrasound examination for defection of flaw (Moscow: LLC "ACS-Service") p 52
- [2] Kozlov V, Samokrutov A and Shevaldykin V 2002 The ultrasonic flaw detection of concrete by the echo method: status and prospects *In the world of nondestructive testing* № 2 p 6
- [3] Samokrutov A and Shevaldykin V 2012 Opportunities of the ultrasonic tomography of concrete (Moscow: LLC "Acoustic control systems") UDC 620.179.16
- [4] Samokrutov A, Shevaldykin V and Kozlov V 2003 Ultrasonic low-frequency piezoelectric transducers with dry point contact and their application for non-destructive testing *Inspection. Trouble shooting* № 2(16) p 30
- [5] Shvabovich K and Suvorov V 2012 Non-destructive testing and plotting of the backwall surface profile using the ultrasound tomography methods (Moscow: LLC "ACS-Service") p 13
- [6] Shtengel V 2002 On the NDT methods and tools for inspection of the operated reinforced concrete structures *In the world of NDT* № 2(16) p 12
- [7] Samokrutov A, Kozlov V and Shevaldykin V 2006 Ultrasonic testing of concrete objects using dry acoustic contact. Methods, instruments and possibilities *The 5th Int. Conf. on Non-Destructive Testing and Technical Diagnostics in Industry* (Moscow) p 152
- [8] Schabowicz K and Hoła J 2012 Nondestructive elastic-wave tests of foundation slab in office building *Materials Transactions* vol. 53 p 296