CHAPTER 6

EXPERIMENTAL STUDIES USING

ULTRASONIC PULSE ECHO

6.1 GENERAL

Ultrasonic Pulse Echo (UPE) technique is a one sided method used for thickness measurement of concrete members, detection of voids and post tensioned ducts in concrete. With the advancement in data processing, the images in the form of B-scans and the C-scans can be obtained. UPE techniques with both the equipment A1220 Monolith and MIRA tomography system were used for the evaluation of different parameters of all the four different specimens which were tested using UPV and radar techniques.

6.2 ULTRASONIC PULSE ECHO EQUIPMENT: A1220 Monolith

The equipment used is the low frequency ultrasonic flaw detector for concrete namely A1220 Monolith. The unique feature of A1220 Monolith is that it provides testing at one-side access of the testing object, which makes it possible to test concrete structures such as buildings, bridges, tunnels, etc., in situ. Another main advantage of the equipment is that no coupling agent and special preparation of the object’s surface is needed to make investigation. Due to the special structure of antenna array, which is used as transducer with A1220 Monolith, testing on the rough surfaces is possible. A1220 Monolith consists of electronic unit with a screen and keyboard and, an antenna array. The transmitter and receiver are housed in the same unit which consists of a 24 element (6x4) matrix antenna array. The antenna array elements construction allows to test without using any contact liquid, i.e. with dry-point-contact. All of the elements
have an independent spring load, which allows to test on uneven surfaces. Figure 6.1 shows the ultrasonic pulse echo equipment.

![Figure 6.1 A1220 MONOLITH –UPE Equipment](image)

The results of testing are displayed on the liquid-crystal display as A-scans or B-Scans (in modes BAND or MAP, rebuilding the image of object’s section). All the results of testing (signal forms with parameters) can be saved in non-volatile memory of the device and transferred to an external PC for further processing, printing and archiving. Besides, the special software (PLAINVISOR) allows reconstructing the B-scan and E-scan images of the internal structure of the tested object.

### 6.2.1 Features

The device can display the results in different forms as follows:

**i. A-scan form**

The results display in form of an A-scan is convenient for measuring thickness of the object of control, flaw searching and analysis in selected area of the object. The fully digital section of the device can display signals both in detected form and as a radio
signal, which is very important for data analysis. This allows additional possibilities of interpreting the signals, such as differentiating useful signals from noise, and detects signals from various reflectors.

ii. BAND mode-(B-scan)

The display of measurement results of a cross-section is shown in the B-scan. B-scan gives a full image of the internal structure of an object. In this mode it is possible to build the image of the cross section. It is built when the object is scanned with the probe along one line with a fixed step. On the display, the operator can see the image of the section as a binary image. Figure 6.2 shows the band mode. The cross-section on the screen is shown as a binary image, where black pieces mark the places, where signal level is higher than the threshold and the other places stay white. BAND building is convenient when controlling an extensive object of control along one line. The option of getting results in colour mode and in half-tone mode is available with help of an external PC and special software.

![Figure 6.2 Band Mode (Ultrasonic Pulse Echo)](image)

iii. MAP mode

This mode is used, when the operator needs to test the limited area of the testing object. The results are shown in a set of B-scans. The object is scanned along the marked lines with a fixed step. Figure 6.3 shows the display of map mode. An image of
the internal structure can be received. The section image is screened in binary form, on which with the black color the areas of crossing the threshold with the signals are marked; all the other areas are white. After saving this data and transmitting it to the PC it is possible to build the half-toned or color image with the help of the special software.

![Figure 6.3 MAP Mode (Ultrasonic Pulse Echo)](image)

**6.2.2 Making a Measurement**

It is necessary to clean the surface from dust and sand and remove the entire materials from the surface that could prevent low-frequency ultrasonic penetration in the material. When the antenna array is put on uneven surface, all its elements should have contact with the surface. Before scanning with antenna array it is necessary to put the grid lines on the surface of the object. Usually a grid spacing of 25 mm is adopted in X and Y axis. The scanning will be made with antenna array along the marked line with the fixed step. On the screen the operator will get the binary image of internal structure in the scanning plane.

**6.3 ULTRASONIC TOMOGRAPH MIRA SYSTEM (ACSYS, Russia)**

The low-frequency linear ultrasonic tomograph MIRA is a multifunctional focusing array system using shear waves and tomographic methods of signal processing. The tomograph MIRA is used for imaging of the internal structure of objects from concrete and reinforced concrete using pulse-echo technique of testing at one-side access. It is
used to determine the flaws, cracks, honeycombs, positioning of ducts etc., and also to assess the state of reinforcement bars to some extent in concrete. The MIRA tomograph consists of 12 measuring units, combined into a focusing antenna array, controlling unit and interface unit of PC type, which receives and processes signals and controls the operation of the system. The measuring block contains a matrix antenna of 48 (12 blocks with 4 elements in each) low-frequency broadband shear wave transducers with dry contact and ceramic wear-resistant tips. Figure 6.4(a) shows the main unit with a CD scan and Figure 6.4(b) shows the antenna which is fixed on the bottom side of the main unit.

Figure 6.4 a Ultrasonic Tomograph MIRA System

Figure 6.4 b View of various dry point contact (DPC) transducers
6.3.1 Synthetic Aperture Focusing Technique (SAFT) and SAFT-C

Although, concrete is considered an isotropic, elastic solid, where by definition the material properties of the material are independent of direction, the inherent inhomogeneity of concrete, requires many combinations of data points to map out and to accurately reconstruct, an image depicting the internal conditions of a test element. To overcome this obstacle, spatial averaging of a large number of single measurements per unit area is performed using an array of low frequency, short pulse, DPC transducers and a mathematical algorithm known as Synthetic Aperture Focusing Technique (SAFT) is used to generate 2D or 3D images. The method coherently combines pulse-echo measurements at a multitude of transmitter/ receiver locations to form an image of the ultrasonic reflectivity of the test area under investigation. The MIRA’s SAFT algorithm is based on a modified SAFT analysis version known as SAFT-C (C for combinations). The principle of SAFT-C entails the digital processing of simultaneous combinations of test points to enhance the resolution and the signal-to-noise ratio of the final images. The data is collected using a Digitally Focused Array (DFA), the basic principle consists of independently capturing the echo signals from every set (pair) of antenna sensors being triggered, and digitally focusing on each point to visualize the given cross section. The SAFT-C method produces a narrow synthetic beam by the coherent summation of the phase adjusted pulses(A-scans) at different angles. As the first row of transducers produces the pulse, the remaining rows captured the returning pulse at different angles (Figure 6.5).
The full set of received reflections (pulses) contains the signals from all the sequentially increasing combinations of transmitter-receiver pairs of transducers. The total number of combinations between emitting and receiving transducers is given by the following relationship:

\[ N = n(n - 1)/2 \]  \hspace{1cm}  \text{(6.1)}

where \((N)\) is the total number of transducer combinations (emitting and receiving rows) and \((n)\) is the total number of transducer modules or rows. The image reconstruction of the test results is obtained as a B-scan (Figure 6.6).

### 6.4 EVALUATION OF UNIQUE REINFORCED CONCRETE MULTISTORY SPECIMEN

The first floor and second floor slab of the multistory structure were (Figure 4.5 of chapter 4) divided into four portions namely slab1, slab2, slab3 and slab4. Each portion
of the slab was divided into 50mm x 50 mm grid spacing in both the directions. The grids were marked from 1 to 20 in both the directions. Figure 6.7 shows the grid details of the slab. The A1220 Monolith ultrasonic pulse echo system and the MIRA ultrasonic tomography system were used for the data collection and further analysis.

![Figure 6.7 Grid details of the first and second floor slab](image)

6.4.1 Evaluation using A1220 Monolith Ultrasonic Pulse Echo System

The UPE A1220 Monolith was used on the first floor and second floor slab using the commercial available pulse echo system, namely the A1220 monolith. Figure 6.8 shows the data collection using A1220 Monolith equipment. The data was collected at each point and along a line manually. The A-scans and B-scans were obtained in the instrument. After collecting, the data were transferred to a computer and analysed using the post-processing software Planevisor software. The B-scans and C-scans obtained at different locations.
6.4.1.1 First Floor Slab Results

First floor slab has different thickness of 200mm, 300mm and 400mm. Figures 6.9 to 6.11 show the B-scan and C-scan for slab thicknesses of 200mm, 300mm and 400mm respectively.

Figure 6.9 B-scan and C-scan images of first floor slab S1 – 200 mm
6.4.1.2 Second Floor Slab Results

Figure 6.12 shows the back wall i.e. the depth of the specimen is identified as 250 mm from the B-scan. Figure 6.12 shows the presence of PVC pipe in the 250 mm thick slab. The presence of steel box is identified at a depth of 150 mm from top of the slab (Figure 6.13) which has been kept during casting.
6.4.2 Testing with MIRA Ultrasonic Tomograph

The ultrasonic pulse echo tomography MIRA system was used for the evaluation of the thickness and the presence of honeycombs, steel embedments in the specimen. Figure 6.14 shows the measurements with the MIRA ultrasonic tomograph on the top side of the slab.
Figure 6.14 Testing with MIRA Tomograph on the concrete slab

Figure 6.15 shows the B Scan image of the first floor slab. The back wall thickness of the slab is clearly seen as 150 mm. The presence of voids can be seen in the B-scan of Figure 6.16. The reflection of the steel plate embedded in the concrete is clearly seen in the B-scan of Figure 6.17.

Figure 6.15 B-Scan showing the back wall of the slab (150 mm)  

Figure 6.16 B-Scan showing the honeycombs (B) in the concrete slab (150 mm)
Figure 6.17 B-Scan showing the reflection of steel plate in the concrete slab (150 mm)

Figure 6.18 shows the back wall thickness of concrete slab of 250 mm. The presence of the honeycombs (C) and the reflection of the steel box are shown in Figures 6.19 and 6.20 respectively. Thus the honeycombs and the steel embedments present in the concrete are obtained as images in the B-scan which otherwise impossible with the basic UPV method.

Figure 6.18 B-Scan showing the back wall thickness of concrete slab (250 mm)

Figure 6.19 B-Scan showing the honeycombs(C) in the concrete slab (250 mm)
6.5 CONCRETE PRISMS CONTAINING DIFFERENT SIZES OF VOIDS

The concrete prism specimens containing different sizes of cubical voids were evaluated with UPE A1220 Monolith. The details of the specimens HC1, HC4 and HC8 are given in 4.4.1 of Chapter 4. Grid lines of 25mm x 25mm were marked on the specimens and the data was collected with ultrasonic pulse echo system A1220 Monolith. Both BAND and MAP images were collected and analyzed using Planevisor software. The details of test results and its interpretation are given below for HC1, HC4 and to HC8 for different conditions of the presence of voids.

6.5.1 Beam Specimen HC1 (Voids with no reinforcements on top)

Figure 6.21 shows the B-scan and C-scan image of the beam specimen HC1. Depth of the specimen is identified as 300 mm from the back wall obtained from B-scan image. The presence of flaws can be seen from the B-scan and C-scan images. The 75mm void is observed at a depth of 155 mm compared to its actual location of 150 mm.
6.5.2 Beam Specimen HC4 (Voids under 8 mm stirrup)

Figure 6.22 shows the B-Scan and C-scan image of HC-4. Depth of the specimen is identified as 300mm from the B-scan image. Presence of 75mm void is identified from the B-scan and C-scan image.
6.5.3 Beam Specimen HC 8 (Voids under 16 mm reinforcement)

Figure 6.23 shows the MAP image i.e., the B-scan and C-scan image of specimen HC8. Presence of 75mm void is identified at a depth of 109 mm compared to the actual location of 120 mm. The Back wall of the specimen is also identified as 300mm.

![Figure 6.23 B-scan and C-scan image 75mm void- HC-8(UPE)](image)

6.6 CONCRETE BLOCKS WITH DUCT

Two concrete blocks of size 700 mm x 700 mm x 300 mm, one containing empty duct and the other containing duct with half the portion fully grouted and half the portion partially grouted were used for evaluation. The details of these specimens are given in 4.5 of Chapter 4. The grid lines of 25 mm x 25 mm were marked on top of the specimen in both X and Y directions. The readings were collected in BAND and MAP mode with Ultrasonic Pulse Echo A1220 MONOLITH. The Band and MAP readings were processed with PlaneVisor software. The B-scan as obtained from BAND mode is
shown in Figure 6.24a and 6.24b for TD1 and TD2. The back wall and the presence of duct is seen in both the specimens at different depths.

Figure 6.24a  B-scan (Band Mode)- TD1

Figure 6.24b  B-scan (Band Mode)- TD2

Figure 6.25 shows the B-Scan and C-Scan images of TD1. It can be seen that the duct is seen in B–scan and C-scan. There is a discontinuity in the back wall at the location of the empty duct.
Figure 6.25 C-Scan image of TD1 showing duct

Figure 6.26 and Figure 6.27 show the B-scan and C-scan image of TD2. The duct is seen in the C-scan of Figure 6.26. The B-scans are given in two locations along the duct namely in grouted and ungrouted region. It can be seen that there is a discontinuity in the back wall of ungrouted region, whereas the back wall is fully seen in the grouted region.

Figure 6.26 B-scan and C-scan image of TD2 (Partially Grouted)
The TD1 and TD2 were also tested using Ultrasonic tomography MIRA system.

Figures 6.28(a) and (b) show the B-scan for TD1. It can be seen that the duct is seen clearly along with the reinforcements at the sides. There is a break in the back wall at the location of the duct because it is fully ungrouted.

Figures 6.29 (a) and (b) show the B-scan for TD2. It can be seen that the duct is seen clearly along with the reinforcements at the sides. The back wall is clearly seen in Fig. 6.29 (a) at the fully grouted area, whereas there is break in the back wall at the partially grouted regions.
6.7 CONCRETE BLOCKS WITH HONEYCOMBS

The UPE data was collected on the specimen given in 4.6 of chapter 4 with A1220 Monolith in both band and MAP mode and the data was analyzed with the PLANEVISOR software for generating the B-scans and C-scans. Figures 6.30 (a) and (b) show the B-scans for specimens 3A and 3B. The backwall is clearly seen in the solid specimen whereas the back wall is not seen clearly in the honeycombed specimen. Also in the top portions, the dark regions show the presence of honeycombs/voids in the specimen.

The C-scans were obtained for specimens 3A and 3B for different depths namely 50, 100, 150, 200 and 250 mm. The C-scans are the sections parallel to the top surface. Figures 6.31a and 6.31b show the C-scans for different depths. The upper left corner in each of the image is the C-scan and the image below it is the B-scan showing the depth.
Two patterns are shown with different grey scales. It can be seen that the back wall is clearly seen for the solid specimen 3A for all the depths. The same is absent for honeycombed specimen 3B showing the presence of honeycombs/voids. Similarly the dark regions in the C-scans of Figure 6.31b show the presence of voids in specimen 3B.

Figure 6.31 a B-scans and C-scans for Specimen 3A- Solid Specimen
6. 8 SUMMARY

The evaluation of four types of concrete specimens is carried out with UPE A1220 Monloith and the UPE MIRA tomograph system. The first study consists of evaluating the thickness, honeycombs, embedments inside the slab such as PVC pipes, steel box,
etc., with both the systems. Based on the studies, it is concluded that the ultrasonic pulse echo technique provides information on the exact thickness of the concrete member. Embedment such as steel plate and honeycombs can also be identified in the form of B-scan and C-scan images. In the second study, the size of the cubical voids that can be determined using UPE, it was found that a size greater than 50 mm can be evaluated with UPE. Artificially created voids can be located with 97% accuracy when there is no reinforcement above the void and 90% accuracy when the void is under the reinforcement. In the third study, the detection of ducts and the efficiency of the grouting were found with both the UPE systems. The A1220 Monolith is capable of detecting the ducts and the efficiency of grouting. The UPE tomograph also gives the B-scan image at a location instantaneously. The ducts and the efficiency of the grouting can be detected with the UPE MIRA tomography system easily. In the fourth study, it was found that the UPE is capable of detecting the real honeycombs in concrete structure. In the A1220 Monolith, the data is collected at a grid spacing of 25 mm manually and the B-scan and C-scan are obtained with software. In the UPE tomography system, the B-scan image is obtained instantaneously. The presences of voids were found exactly in both the methods of UPE system.