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Complex Research of Concrete Structures with Ultrasound and Geolocation Methods

[1]Nodar D. Varamashvili, [2]Bezhan Z. Asanidze, [3]Mamuka N. Jakhutashvili, [4]Vladimir V. Glazunov

[1] Ivane Javakhishvili Tbilisi State University, Mikheil Nodia Institute of Geophysics, [2] British Petroleum Company (BP), [3] Georgian Technical University, [4]Saint-Petersburg Mining University

ABSTRACT

The subject of our research was to study the current state of the Tsageri catchment, using georadiolocation and ultrasound methods. Georadar Zond 12e was used in the research.. Georadar data were collected and processed with Prizm 2.7 regular Software. With the help of georadar, it is possible to highlight voids, cracks and weakened environment. It is also possible to determine the degree of humidity of the environment. Antennas of different frequencies are used to study different environment. By our research was used 1 MHz, 1.5 MHz and other frequencies antennas. Ultrasonic method is also an effective tool for determining the mechanical parameters of the environment and itsl structure. In the presented works, the ultrasonic equipment manufactured by the Swiss company PROCEQ, pulsed echo transmitter - Pundit PL-200PE was used. Processing of the obtained material was performed by means of the Pundit - 200 and Pundit - 20PE working program "PL-Link". Using ultrasonic equipment, it is possible to highlight voids and cracks in the environment and study their geometrical parameters. as well as determining the mechanical characteristics of the environment. When studying the same areas, the results obtained by radar and ultrasonic methods correlate quite well with each other in terms of determining the structure and complement each other in terms of determining the mechanical parameters of the medium and details of the structure.

Key words: *tomography, ultrasonic, georadiolocation, GPR, nondestructive testing*

Introduction

Ultrasound corresponds to a mechanical wave propagating at frequencies above the range of human hearing (conventionally 20 kHz). Ultrasound and sound waves propagate in fluids (gases and liquids) and solids. In particular, the wave propagation depends on the intrinsic elastic properties of the medium as well as on its mass density. In addition to its widespread use in engineering applications (e.g., defect detection / evaluation, material characteristics, etc.), ultrasounds are also used in the medical field. In general, ultrasound testing is based on the recording and quantification of reflected waves (pulse-echo) or transmitting waves [7].

A ultrasonic pulse-echo test concentrates on measuring the transit time of ultrasonic waves traveling through a material and being reflected to the surface of the tested medium. Based on the transit time or velocity, this technique can also be used to indirectly detect the presence of internal flaws, such as cracking, voids, delamination or horizontal cracking, or other damages [7,9].

Each of the two types is used under certain conditions [4,5]. In our scientific research, we use acoustics for geophysical and geotechnical research [1,3,5]. In this paper we present scientific-applied studies in the field of geomechanics using acoustic methods [6].

Equipment and software for ultrasound examination

We used ultrasound equipment produced by the Swiss company (PROCEQ, https://www.proceq.com/) for geophysical work, called Pundit PL-200 and Pundit PL-200PE. Ultrasonic testers (Pundit PL-200 and Pundit PL-200PE) are used to study concrete, wood and stone materials and structures using non-damaging acoustic control methods. Equipment and methods can be used: to study internal defects and cracks, heterogeneities and voids in materials, to calculate material modulus, stiffness and Poisson's ratio.

Pulse Echo Transducer - Pundit PL-200PE

The Pulse Echo transducer is a shear wave transducer designed for single-handed and two-handed operation. It is particularly suited to testing where access is limited to a single side.

The Pundit PL-200 offers three methods of transmission.

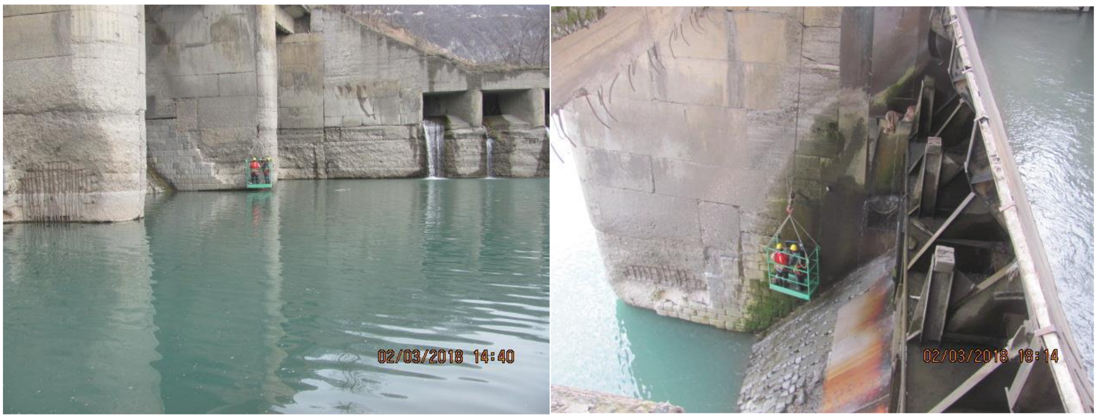
Ultrasonic research methods

In our case, we used ultrasonic sounding with piezoelectric 54 kHz sensors. Piezoelectric transverse wave sensors with a frequency of 250 kHz were also used, and piezoelectric sensors with a frequency of 50 kHz were used for ultrasound tomography. With the help of sensors in such frequency ranges, it is possible to study the structure of a solid and concrete at a depth of 50-60 cm, and in some cases even up to 1 m.

Performing ultrasound examinations

Ultrasound examinations were performed on the load-bearing piers and walls of the Tsageri catchment (Fig. 1). Approximately 100 sites were selected in the vertical direction on the walls of the building where the mechanical properties of the concrete were studied.

a.



b.

Fig. 1. a) Tsageri catchment. 1 - East wall, 2 - First (east) pier, 3 - Second (central) pier, 4 - Third (west) pier and 5 - West wall. b) A picture of the ultrasound work on the load-bearing piers and walls of the catchment dam.

About 100 areas were selected in the vertical direction on the walls of the building, where the mechanical characteristics of concrete were studied. In addition, a network of profiles with a step of 0.05 m was carried out on the piers and walls of the reservoir, using the tool. For the further processing of the obtained materials, the values of the velocity parameters of the elastic waves were entered into the existing program, and as a result, the elastic parameters of the reinforced concrete constructions were obtained. Since the velocities of P and S type elastic waves are theoretically and empirically related to the elastic parameters of the environment, we can judge the presence of weakened, exhausted and relatively damaged zones within the investigated area. Using the sensors designed to generate and receive longitudinal (P) and transversal (S) type of elastic waves of the mentioned device, coverage (sensing) works were performed on the visually preserved and weakened areas of the walls of the building.

With the obtained materials, the propagation velocities of P and S type elastic waves were determined, both in concrete and in the blocks of granite stones near the aqueduct. Based on these velocities, the following physical-mechanical parameters were determined for all tested objects: ρ - density, ν - Poisson's ratio and E - Young's dynamic modulus. Poisson's ratio was used to determine the quality of concrete. Its value is in the range of (0.15-0.20) for normal quality concrete.

Data processing

Ultrasound waveform and tomographic (B-scan) recordings (Fig. 2) were processed using (PL-Link) standard software.

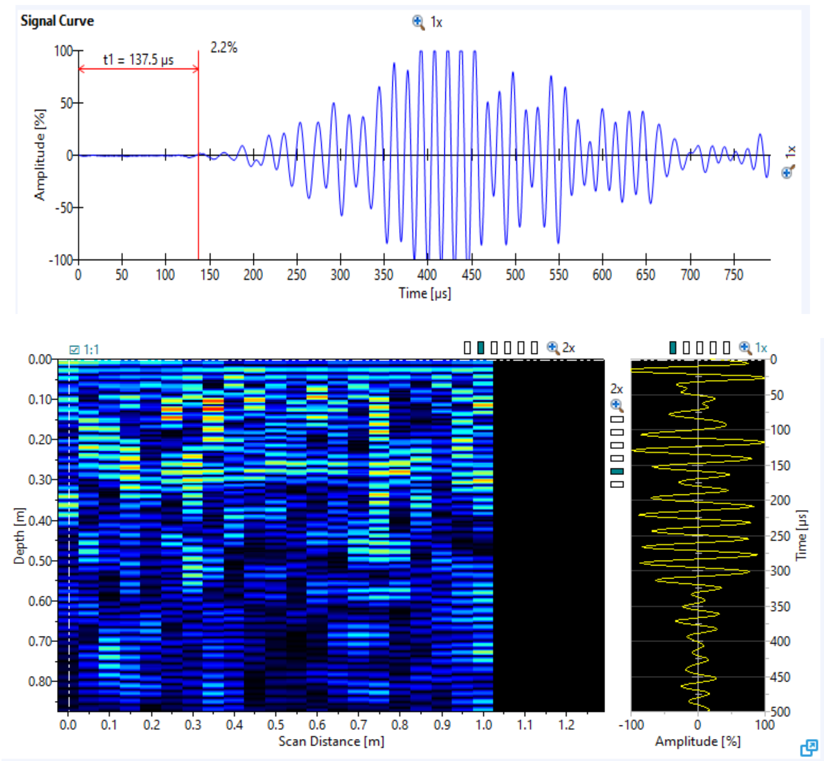


Fig.2. Ultrasound waveform (upper) and tomographic (lower) recordings.

On the records of oscillograms, the separation of longitudinal and transverse waves took place, their velocities were determined and various elastic parameters were calculated on the corresponding profiles. T On the processing and analysis of tomographic recordings (B-scans) took place us to identify possible voids, heterogeneous and weakened areas in the concrete.

Results of ultrasound examinations

About 100 precincts were processed. The image presented for each precinct is indicated by brown lines indicating the relevance of the tomographic images to the profiles. The yellow lines indicate the correspondence of the longitudinal velocities and the Poisson ratio with the profiles. The probable damaged areas localized by the velocity measurement are highlighted in blue, while the probable damage and weakening localized at different depths in the concrete pavement are marked in red by scanning. Here we present two of the location.

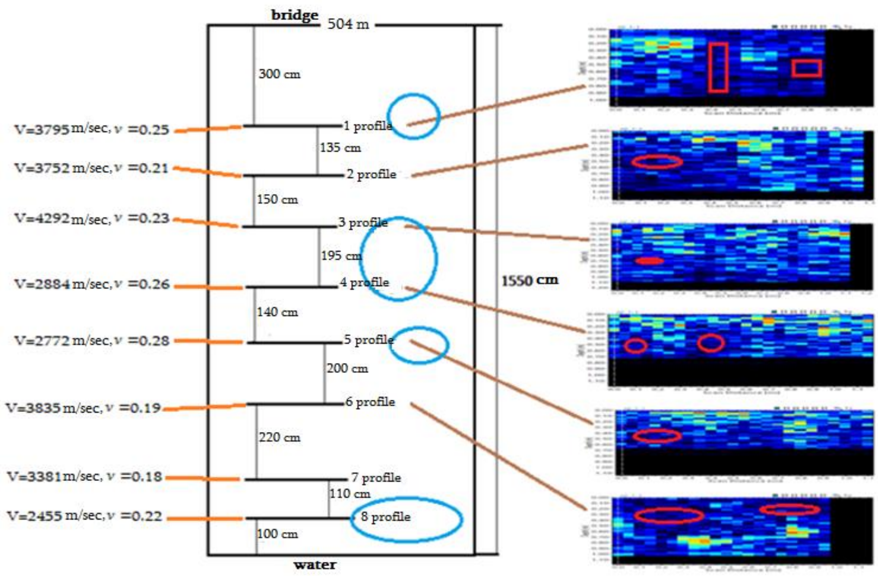


Fig.3. Profiles and tomographic records of one areas of the catchment. (Plot #5. The western wall of the second (central) pier of the reservoir).

Ultrasound testing works were performed on eight profiles at this site. Longitudinal (P) wave velocities in different profile ranges vary from 4292 m / s to 2455 m / s, transverse 2541 m / s to 1483 m / s, Poisson's ratio (ν) from 0,26 to 0 , At 18 intervals, and the Ju ng modulus (E) - (11639-39857) in the MPa interval.

One and more measurements of ultrasonic wave velocities were performed on all profiles in this area. They are made on concrete slab, on "poured concrete" and in the area of transition from concrete to tile. As the transition from the upper profiles of the precinct to the lower profiles, a gradual change in the speed of the ultrasonic wave will be observed. The velocity values are reduced in the vicinity of the third and fourth profiles. The values of the Poisson's ratio change in the range of 0.21-0.28 in the areas of the top five profiles, which probably indicates a weakening of the concrete structure in these areas. The velocity decreases particularly in the vicinity of the eighth (bottom) profile, which probably means damage to the concrete at this site or deterioration of its structure in this part of the pier [8].

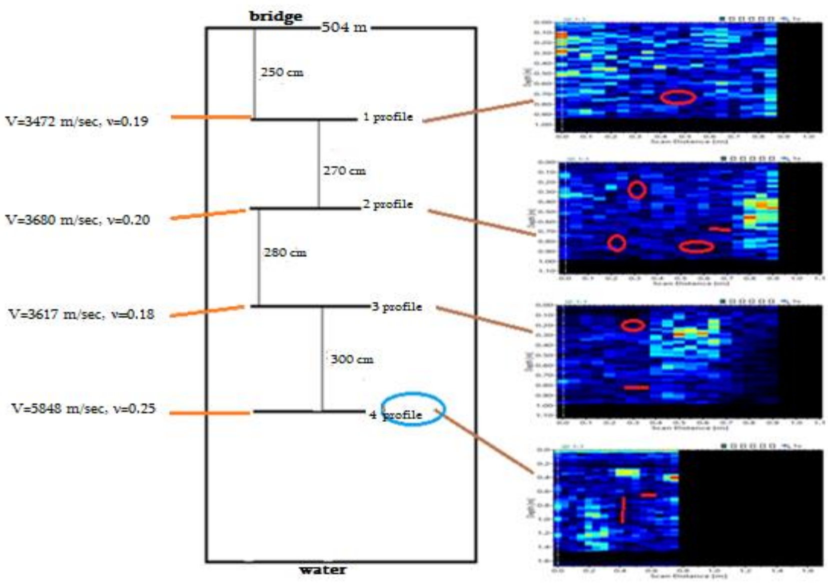


Fig.4. East wall (on the side of the dam) profiles of the first catchment tower and tomographic record of some profiles. (Plot #5. The western wall of the second (central) pier of the reservoir).

At this site (Fig.5) ultrasonic measurements were performed on three profiles along the wall and on the fourth profile on granite stones. Normal values of the Poisson's ratio (0.18-0.20) were be observed on all profiles and almost all measuring points, indicating the stability of the mechanical parameters of the concrete - its good condition. Ultrasound tomography (B-scan) was also performed on this incision. Deep lesions of different nature were observed in the tomographic images of all profiles, at different depths, as indicated in the images. In the tomographic images, in addition to the marked areas, dark colored areas was observed, which should indicate their weakening [8].

Comparison of the data presented in the two precincts (Fig.3, Fig.4) shows that they are relatively different precincts. The mechanical parameters of the bearing concretes in these areas differ from each other and indicate different mechanical states of the different catchment areas.

Conclusion

1.Modern methods of ultrasound examination and tools used have been found to be effective in assessing the condition of concrete structures constructing piers and walls.
2. The measurement results give different values of the elastic parameters. Tomographic scan images have abnormal areas. These anomalous areas must be associated with changes in the structure of the concrete.
3. A sharp change in the values of the Poisson's ratio should also be associated with a change in the rigidity of the material of the studied objects and its structure.
4. In general, it can be said that the results of the examination of the objects under study confirm that the physical and mechanical parameters are more abnormal in the areas adjacent to the lower, blurred-erosive areas than in the areas of concrete slabs above.

The results of checking the concrete mark on the supporting constructions of the research areas.

The purpose of the conducted research was to evaluate grade the used concrete on both the east and west walls, as well as on the piers. The need for this arose after visual inspection of these structures revealed defects. In modern conditions, it is possible to check the density (mark) of concrete products with different types of field tools. One of these types of tools is the Schmidt hammer (photo 5).

Fig. 5. The appearance of the Schmidt hammer.

The advantage of this tool is that in a short time, the strength/grade of the concrete structure can be determined without disturbing the integrity of the product.

The physical basis for the operation of this device is based on the amplitude of its reflection (recoil) when a solid body is struck by a solid surface. Accordingly, the greater the density (strength) of concrete, the greater the amplitude of its reflection and the data on the scale.

During the observation, measurements were made along the surfaces both on the slabs and on the reinforced concrete structures on the south side and lower sections.

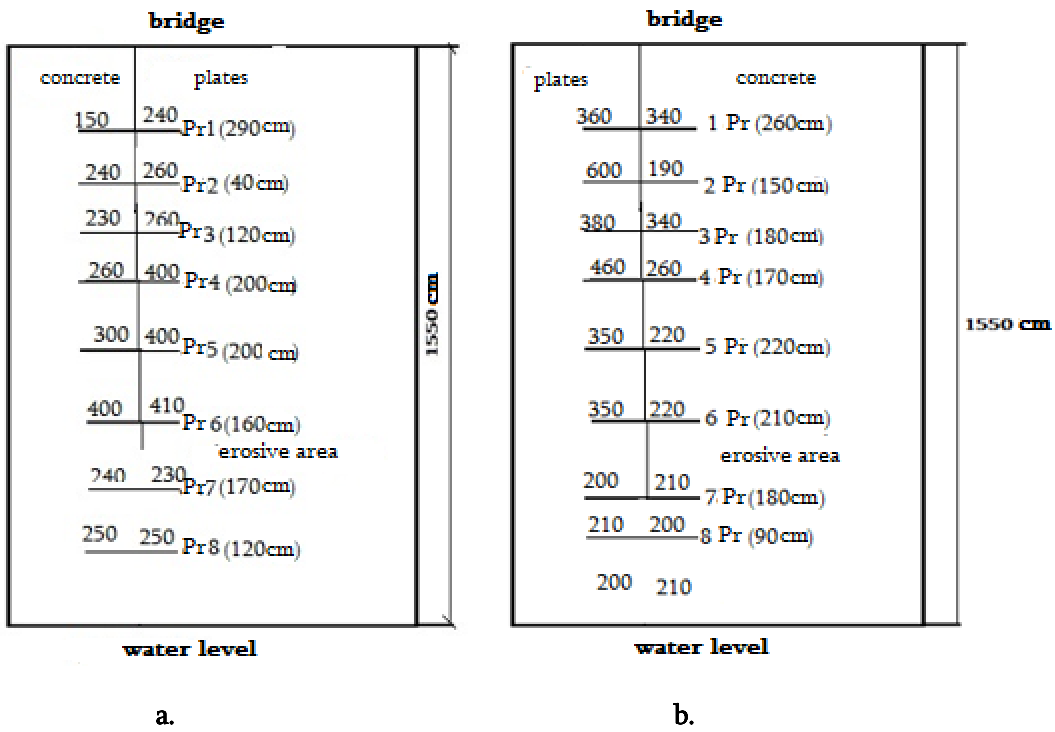


Fig. 6. The results of checking the concrete mark on the east (a) and west (b) side of the first pier (schematic sections).

For the slabs of the first pier, the grade of concrete varies mainly from 240 to 600, and from 210 to 340 on the south side and sides and washed-eroded sections of concrete. Above it, at a depth of 5-5.5 m from the level of the bridge, on the western side, higher values were allocated within the range of 300-340. On the lower, eroded-washed-faulty sections, its value is low here too (within 200-240).

On the basis of the research conducted with the Schmidt hammer on the surfaces of the retaining walls and piers of the dam and the analysis of the obtained results, the following can be concluded:

1. The concrete grade is characterized by higher values for the slabs placed outside the walls and piers than for the rest of the construction surfaces and areas without it.
2. Particularly low values of the concrete grade were revealed for the eroded-washed sections of the eastern and western walls, as well as in the lower sections of the piers.

In our opinion, the change in such a wide range of concrete grades does not correspond to either the old or the new norms of construction. Their causes can be: discrepancy of the cement brand, its insufficient concentration or flaws in the construction technology.

Georadiolocation research

Georadiolocation method has high spatial resolution [10]. There is no limitation on the daily surface and on the surface of different types of artificial cover, as well as in water surface or underwater research.
In our work, georadiolocation research was carried out in the following ways:

1. Hydrogeographic survey from the water surface in the basin.
2. Underwater research from the bottom of the pool to the surface of the water
3. Vertical survey along walls and supporting piers.

Georadiolocation along the terrain on the daily surface.
The selected georadiolocation method and their varietis allowed us to obtain a continuous georadiolocation cut, which reflects the structure of the ground, the structure of the reinforced concrete structure and the study of the underwater space to the maximum possible depth, which is determined by the electrophysical properties of the soil, concrete and water.
The number of profiles, their location, length and orientation for each object under study was carried out independently, taking into account the type of surface and technogenic factors.
Georadiolocation studies were carried out with profile and area planning.

For our article, the part of the profile study that was implemented on the pool walls and supporting piers is interesting.
Georadiolocation method is based on the registration of electromagnetic (EM) nanosecond pulses propagation in the studied environment and further processing taking into account the electromagnetic properties.
Screened antenna blocks with frequencies of 300, 900, 1000 and 1500 MHz were used in georadiolocation studies.

Georadiolocation equipment and software.

A certified "ZOND-12e Advance" (Ltd. "RadarSystemInc", Riga, Latvia) with screened antennas was used for geophysical research. Management of geo-radar, data processing, visualization of georadarograms is performed with the help of certified computer program «PRISM v.2.60» (Ltd. «Radar System Inc»). This type of georadar is certified in the European Union. It has antennas of different frequencies to penetrate to different depths and to conduct different types of research. In this article, we are interested in comparing the results obtained with ultrasound and georadiolocation equipment, so we will consider only the vertical planning along the walls and supporting piers conducted with 1 and 1.5 gigahertz antennas.

Fig. 7. 1 GHz antenna and 1.5 GHz antenna with its own odometer wheel.

Surface georadar surveys of walls and piers are carried out with the help of a 1000 MHz antenna. A 1500 MHz antenna has also been used for testing on the second pier. During research with this method, the antenna was removed from the surface of the wall by a minimum distance and moved along it.

Fig. 8. a) Georadar research process along the second pier (using 1000 MHz antenna), b) low-threshold dam condition investigation process using 1000 MHz antenna.

During the georadio-radar profiling of the low-threshold dams located at the base of the first and second barrier shields, the geophysical team, with the help of a crane, descended to the level of the dam and moved the 1000 MHz antenna along the inclined surface from the ground up, along its entire length, by means of a designated cable-rope with markings of meters (Fig. 8).

Results of georadiolocation investigation

The results of the main georadiolocation survey are presented in the form of georadiolocation section profiles. The types of wave EM fields correspond to different types of concrete, as well as reflect their uniformity and moisture content. Along the supporting piers and walls, the location of the iron reinforcement grids and metal elements supporting the walls is characterized. Below, the results of the georadiolocation survey are described according to the respective areas.

Georadiolocation investigation results of the walls and piers of the dam

The results of the georadiolocation survey of these objects are presented in the form of cuts on Figures 9-15. Diffraction effects of waves characteristic of armature rods are clearly visible on them (diffraction hyperbolas, Fig. 9). With this method and with the help of the antenna, the location of the reinforcement rods arranged in the profile was well defined.

According to the type of arrangement of reinforcement rods, two types of reinforcement were identified: walls (a) and piers (b) Fig.9). The first type of reinforcement is characterized by the arrangement of small-diameter iron reinforcement rods close to the surface in the form of a grid (type 1). This type is typical for the concrete slabs on the walls and the sections towards the bottom of the pier.

The second (type 2) is characterized by an irregular and deep placement of the reinforcement rods. The amplitude of the change of the EM wave field on this type of constructions is characterized by low intensity, technological boundaries, flaws and layering will be observed in the concrete structure.

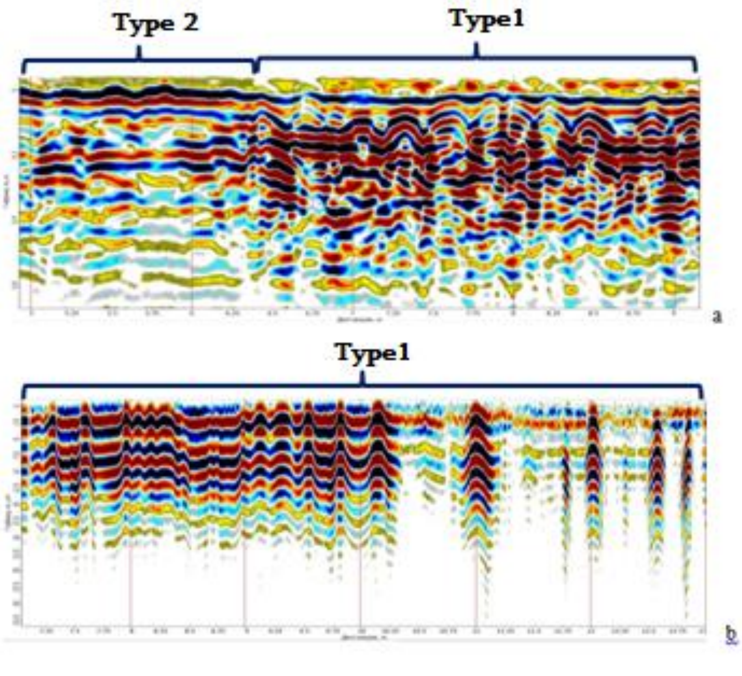


Fig. 9. Fragments of geolocation slices obtained with the help of 1000 and 1500 MHz antennas. The drawing shows two types of reinforcement of concrete structures: eastern wall (a) and piers (b).

Type 1 and 2 intervals are separated by vertical arrows on georadiolocation cuts Pr1 and Pr2 of the eastern wall. The numbers next to the arrows show the appearance of reinforcements.

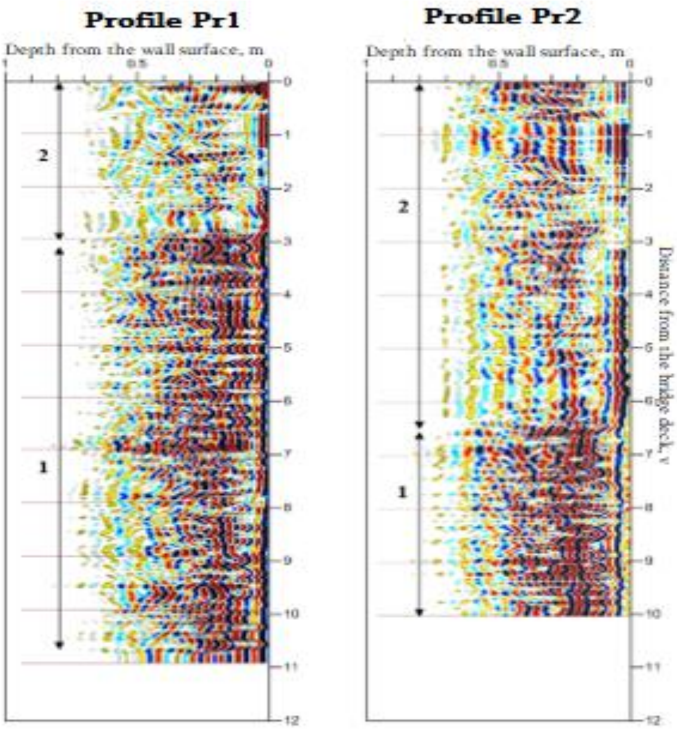


Fig. 10. Georadiolocation slices Pr1 and Pr2 taken along the eastern wall.

Corresponding reinforcement types (1 and 2) were not identified on the profiles (Pr3 and Pr4) obtained for the above-water sections of the first pier. Depending on the nature of the wave field, the second type of reinforcement can be seen here.

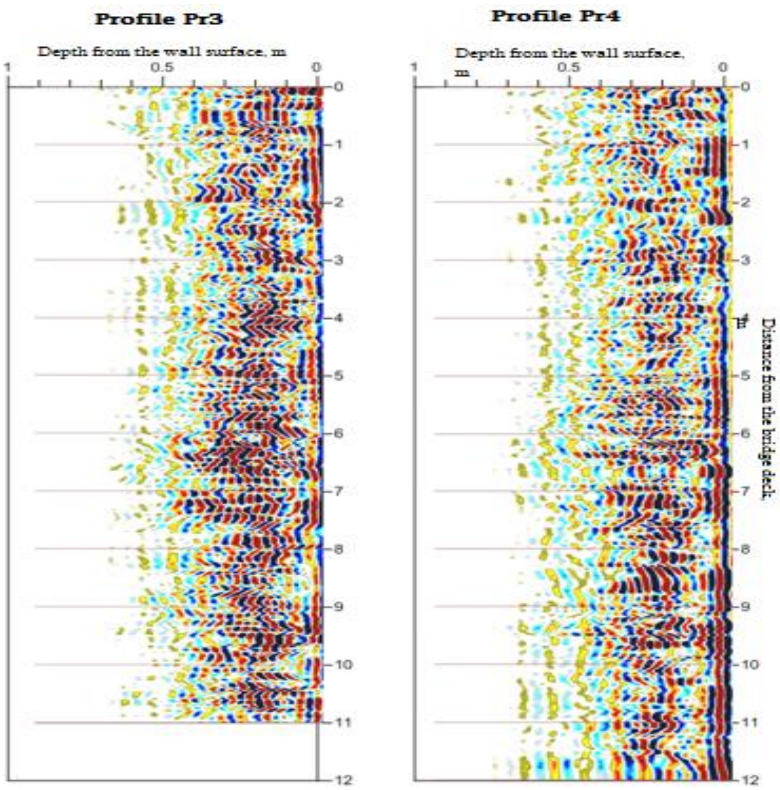


Fig. 11. Georadiolocation slices Pr3 and Pr4 obtained along the first pier.

Sections of type 1 and 2 reinforcements are separated along the georadiolocation cuts Pr5 and Pr6 obtained along the surfaces of the above-water parts of the second pier. The arrows on these slices are conventionally marked as dots, because the effect of individual reinforcement was not sufficiently reflected on them. In order to clarify their boundaries, additional georadiolocation surveys were conducted along these profiles using a 1500 MHz antenna (Figure 12).

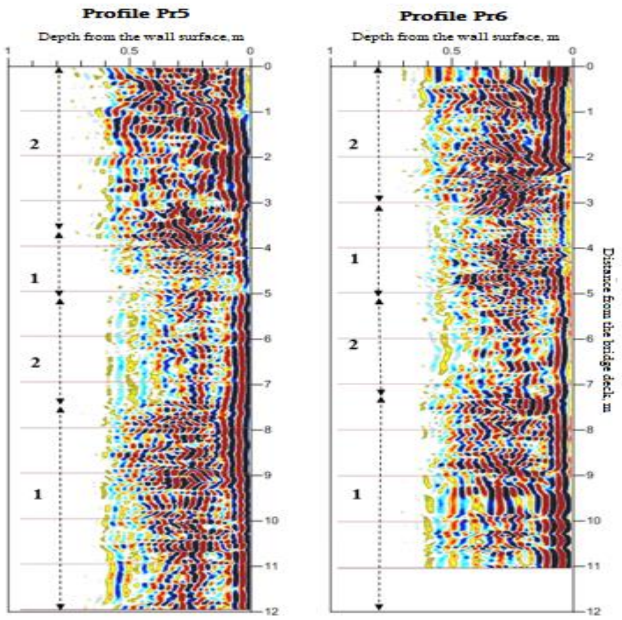


Fig. 12. Georadiolocation slices taken along the second pier (Pr5 and Pr6).

Sections of type 1 and 2 reinforcements are separated by vertical arrows Pr7 and Pr8 along the georadiolocation slices taken along the surface of the third pier's above-water part. The types and intervals of these reinforcements are almost similar to the results of the survey of the second pier (Fig. 13).

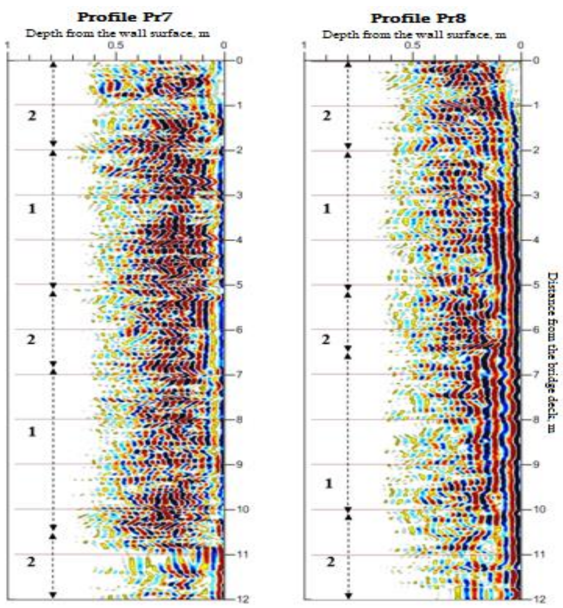


Fig. 13. Georadiolocation slices taken along the third pier (Pr7 and Pr8).

On georadiolocation slices (Pr9 and Pr10) obtained during the survey of the above-water part of the western wall, the reinforcement intervals of type 1 and 2 were well distinguished. They are separated by vertical arrows (Fig. 14).

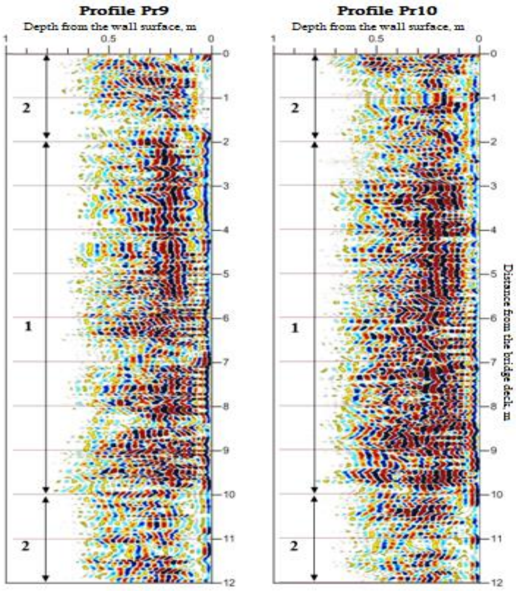


fig. 14. Types of reinforcement found along the western wall along Pr9 and Pr10.

Along the second pier, in its above-water part, we additionally conducted geolocation studies with the help of a 1500 MHz antenna. On the georadiolocation profile (Pr5) obtained by this method, the diffraction hyperbolas caused by the presence of reinforcement rods clearly appeared (Fig. 15). These georadarograms also showed intense, disturbing reverberation waves, which must be due to insufficient (not tight) contact between the antenna and the surface of the pier during investigation.

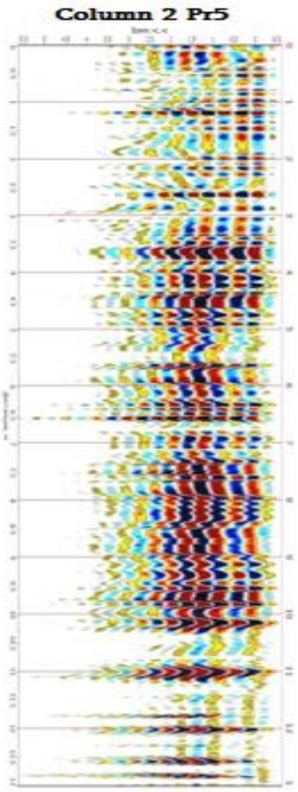


Fig. 15. Georadiolocation profile (Pr5) obtained by means of 1500 MHz antenna along the above-water part of the second pier.

Based on the georadiolocation studies, we can conclude the following:

1. Georadiolocation research method and selected equipment proved to be effective for researching the condition of Lajanur Dam structures located in Tsageri district. In particular:
2. We investigated the condition of the underwater and above-water parts of the supporting piers and the eastern and western walls, their washing depth, the arrangement and frequency of the horizontal bars of the reinforcing mesh of reinforced concrete structures. This part of the research is directly related to the topic of our paper.
3. We were given the opportunity to study the condition of the downstream located in front of the shutter shields, the configuration, depth and width of its damaged bottom.
4. Condition of low-threshold dams 1 and 2 under shutter shields.
5. Ground structure of the three areas surrounding the derivation channel and the filtration areas under the ground.

Conclusion

1. As a result of the ultrasound work, different types of damaged strength and weakened areas of the structure were identified on the piers and supporting walls. Damaged areas were mainly detected near the water surface, in the lower (489-492m) sections of the piers and walls, in the vicinity of washed-eroded areas and also at different heights. The entire vertical section of the eastern and western wall structures is characterized by a weakened structure. Here, the value of Poisson's ratio is significantly increased on the profiles sampled in the interval from 504m to 489m.
2. A relatively better quality concrete structure was found on the north side of the first pier, in the vicinity of the shutter shield along the vertical cut of the entire wall. This is confirmed by the results of both the Schmidt hammer test and the ultrasound survey.
3. The slabs placed outside the walls and piers are characterized by high concrete grade values. Their change is within 260-600. Particularly low concrete grade values were found for the eroded-washed areas of the eastern and western walls, as well as in the lower sections of the piers. In these sections, the grade of concrete varies between 150-220. The causes of these anomalies can probably be: incompatibility of the cement brand, its insufficient quantity or technological violations made during the construction.
4. With the georadiolocation method, the solution of a wide range of engineering and technical tasks can be successfully implemented at various sites and facilities. It can be used in other regions as well, for the purpose of research and diagnosis of the state of hydrotechnical structures of this type.
5. The results of the radiolocation and ultrasound research of the above-water part of the supporting piers and walls are quite well correlated. In addition, these two methods complement each other. Ultrasonic and Schmidt hammer research provides additional information on the mechanical parameters of reinforced concrete for piers and walls. And georadar allows to quickly determine inhomogeneities and defects in reinforced concrete supporting piers and walls.

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ბეტონის სტრუქტურების კომპლექსური კვლევა ულტრაბგერითი და გეორადიოლოკაციური მეთოდებით

ნ. ვარამაშვილი, ბ. ასანიძე, მ. ჯახუტაშვილი, ვ. გლაზუნოვი

რეზიუმე

ჩვენი კვლევის საგანი იყო, გეორადიოლოკაციური და ულტრაბგერითი მეთოდებით, ცაგერის წყალშემკრების თანამედროვე მდგომარეობის შესწავლა. გამოყენებულ იქნა გეორადარი Zond 12e. გეორადარული მონაცემები შეკრებილ და დამუშავებულ იქნა საშტატო კომპიუტერული პროგრამული უზრუნველყოფით Prizm 2.7. გეორადარის საშუალებით შესაძლებელია სხვადასხვა გარემოში არსებული სიცარიელეების, ბზარების, შესუსტებული გარემოს გამოყოფა. შესაძლებელია ასევე გარემოს დატენიანების ხარისხის განსაზღვრა. გეორადილოკაციის მეთოდით სხვადასხვა გარემოს შესასწავლად გამოიყენება სხვადასხვა სიხშირის ანტენები. ჩვენი კვლევისას გამოყენებული იქნა 1 მგჰც, ა.5 მგჰც და სხვა სიხშირის ანტენები. გარემოს მექანიკური პარამეტრების განსაზღვრისათვის და მისი სტრუქტურის დადგენისთვის ასევე ეფექტური საშუალებაა ულტრაბგერითი მეთოდი. წარმოდგენილ სამუშაოებში გამოყენებული იქნა შვეიცარული კომპანიის PROCEQ-ის მიერ წარმოებული ულტრაბგერითი აპარატურა, იმპულსური ექო გადამწოდი - Pundit PL-200PE. მიღებული მასალის დამუშავება შესრულდა Pundit - 200 და Pundit – 20PE-ს სამუშაო პროგრამის “PL-Link” საშუალებით. ულტრაბგერითი აპარატურით შესაძლებელია გარემოში არსებული სიცარიელეების, ბზარების გამოყოფა და მათი გეომეტრიული პარამეტრების შესწავლა. ასევე გარემოს მექანიკური მახასიათებლების დადგენა. ერთი და იგივე უბნების კვლევისას რადიოლოკაციით და ულტრაბგერითი მეთოდებით მიღებული შედეგები ერთმანეთთან საკმაოდ კარგ კორელაციაშია სტრუქტურის დადგენის თვალსაზრისით და ერთმანეთს ავსებენ გარემოს მექანიკური პარამეტრების და სტრუქტურის დეტალების განსაზღვრის კუთხით.

საკვანძო სიტყვები: ტომოგრაფია, ულტრაბგერითი, გეორადიოლოკაცია, GPR, არადესტრუქციული ტესტირება

Комплексное исследование бетонных конструкций ультразвуковыми и геолокационными методами

Н.Д. Варамашвили, Б.З. Асанидзе, М.Н. Джахуташвили, В.В. Глазунов

Резюме

Предметом нашего исследования было изучение современного состояния водосбора Цагери методами георадиолокации и ультразвука. В исследованиях использовался георадар Zond 12e. Данные георадара собирались и обрабатывались с помощью штатной программы Prizm 2.7. С помощью георадара можно выделить пустоты, трещины и ослабленную среду. Также возможно определение степени влажности окружающей среды. Антенны разных частот используются для исследования разных сред. При нашем исследований были использованы антенны 1 МгГц, 1.5 МгГц и других частот. Ультразвуковой метод также является эффективным средством определения механических параметров окружающей среды и ее строения. В представленных работах использовалось ультразвуковое оборудование производства швейцарской фирмы PROCEQ, импульсный эхопередатчик - Pundit PL-200PE. Обработку полученного материала проводили с помощью рабочих программ Pundit-200 и Pundit-20PE «PL-Link». С помощью ультразвукового оборудования можно выделить пустоты и трещины в окружающей среде и изучить их геометрические параметры, а также определить механические характеристики окружающей среды. При исследовании одних и тех же участков результаты, полученные радиолокационным и ультразвуковым методами, достаточно хорошо коррелируют между собой в части определения структуры и дополняют друг друга в части определения механических параметров среды и деталей строения.

Ключевые слова: томография, ультразвук, георадиолокация, георадар, неразрушающий контроль.