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Using Ground Penetrating Radars to Detect Cold Joints in Reinforced Concrete Structures

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Abstract. This research project aims to solve potential problems that may accompany the inspection of a foundation, to increase awareness about ground-penetrating radar surveys and their methods that can help to enhance processes in the inspection process. For the detection of internal defects, a method of ground penetration radar surveying was used, performed using a regular mesh of orthogonal projections over an easily accessible surface area of the slabs and several antennas producing sounding signals with frequencies varying within the range of 1,500 and 2,000 MHz. The results of several field studies were analysed and summarized.

Some internal defects have been detected in the structures, including horizontal cold joints, cavity pockets and honeycombs. Their presence was later confirmed by control drilling and core material sampling. The information thus obtained was later generalized and created surface maps of cold joints that depicted both the relief and the layout of detected defects in space. The core analysis has proven that the reflecting boundaries are the same as those of the core material destruction; it has also demonstrated the presence of air bubbles and the proofs of poor-quality concrete mix compaction.

As a result of the research, it can be established that the use of GPR allows one to effectively detect the presence of cold joints in concreting caused by significant pauses in concreting structures.

Keywords: Cold joint · Concreting pause · GPR · Ground penetrating radar · Internal defects · Slab

1 Introduction

Joints are necessary in reinforced concrete structures for a variety of reasons. Not all RC structures can be placed continuously, so there are construction joints that allow work to resume after a period.

In slabs concrete is cast in a gradual time so that several layers are formed where the boundary between these layers is better known as a cold joint. Cold joints usually form when we have pause in concreting between layers.

According to GOST R 57359-2016/EN 13670:2009 Concrete structures. Execution rules: '… To prevent the formation of cold joints …, it is necessary to choose the appropriate speed to lay and compact the concrete mixture…'. A cold joint may form

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during the concrete works if the concrete mix is placed before the next layer of the concrete mix is laid and compacted.

The literature overview shows that cold joints in concrete significantly affect the performance and durability of RC structures.

1) The longer the casting pause time used, the lower the compressive strength and flexural strength values (Zega et al. 2021).
2) With an increase in the time between pouring two layers of concrete, the compressive, tensile, and flexural strengths of the concrete decreased.
3) Cylinders with horizontal cold joint subjected to compressive strength do not show a loss of resistance in any case (A. Ramos-Cañón et al. 2016).
4) Cold joint formation affects more splitting tensile and flexural concrete strengths rather than compressive strength.
5) The pullout strength between the concrete and the steel bar was weakened by the formation of the cold joint, and the pullout strength decreased as the time of formation of the cold joint increased (lknur Bekem Kara).
6) Cylinders with diagonal joint subjected to compressive strength and with vertical joint subjected to indirect tensile strength did present a great loss of resistance (up to 30% and 42%, respectively) (A. Ramos-Caón et al. 2016).

At the same time, there are no clear instructions in the design codes of different countries for the calculation of cold concrete joints. In the American ACI 224.3R-95, there are general recommendations regarding the arrangement of concreting joints and requirements for surfaces, but there are no methods for calculating cold concreting joints formed in non-project places. In the Soviet Union, there was a design guide to SNiP 2.03.01-84 on the design rules of composite precast and in-situ reinforced concrete structures, which contained a method for calculating shear joints. Currently, the Russian Federation has SP337.1325800.2017 for the design of composite precast and in-situ reinforced concrete structures, which presents a method for calculating the joints for shear.

2 Research Methods

Geophysical methods of non-destructive quality control of the construction of reinforced concrete structures are widely used in the practice of construction in Russia and abroad [1–3]. For the inspection of buildings and structures, the most developed practice is the use of methods based on the analysis of directed elastic electromagnetic waves using ground penetrating radars (GPR).

Geophysical research methods are recommended for use in Russian regulatory documents, but they relate to the soils. Unfortunately, for now in the Russian Federation there are no regulatory documents containing requirements for the practice of using GPR methods in the inspection of structures, like existing standards, such as ASTM D5882 [4]. The development of normative and technical documentation on geophysical methods for quality control is carried out at the level of individual organizations and for certain departments and structures [5].

The possibility of expanding the scope of the GPR method for examining structures and identifying hidden defects is regularly considered in the scientific literature [6, 7].

Because the GPR method is indirect, the possibility of its use for the inspection of structures is often questioned and attributed to the limitations of the method. However, the results of field work demonstrate the possibility of obtaining data in several cases [8–10] that allow us to determine the structure of the structure, the presence of hidden defects, thickness, assess the continuity of the material, and even determine the presence of internal composite reinforcement [11].

3 Field Studies

This section presents typical studies on the detection of cold concreting joints in real objects using GPR technique.

3.1 Foundation Slab #1

The surveyed building structure is a cast-in-place reinforced concrete foundation slab that serves as a slab on piles for a 25-storey residential building under construction. The considered foundation plate has dimensions of 47.42 × 18.12 m and thickness of 1.2 m.

The study of the foundation plate was caused by its prolonged concreting and the formation of a visible cold joint on the side surface and under the upper reinforcing mesh, detected during the author’s supervision and construction control.

The reinforcement of the foundation slab is presented by two steel bar meshes - upper and lower. The main upper and lower reinforcement of the slab is made by reinforcement Ø22 of grade A500C with a spacing of 250 mm in the longitudinal and transverse directions. Bent U-shaped reinforcing elements from Ø22 grade A500C are installed at the edges of the slab. Due to the large thickness of the slab in the middle zone for the distribution of heat generated during the hardening of concrete, an additional structural mesh of rods Ø12 grade A500C with a spacing of 400 × 400 mm was installed. Straight rods Ø12 of grade A500C were also additionally installed on the side surface of the grillage. The concrete cover to the lower reinforcement of the lower mesh is 50 mm, to the upper - 45 mm, to the side - 40 mm.

Driven reinforced concrete piles according to the 1.011.1–10 series, issue 8, of a square cross-section with a size of 350 × 350 mm and a length of 22.0 m were adopted as the base of the examined building. Piles are made of concrete of grade B25 compressive strength, grade W10 for water resistance, grade F100 for frost resistance. Piles are reinforced with non-stressed longitudinal working rebars Ø22 grade A400 (A-III). Piles are installed on a grid with a spacing of 1.2–1.6 m.

To assess the technical condition of a cast-in-place foundation slab, GPR measurements were carried out using a regular network of orthogonal profiles on the surface of the slab (Fig. 1). The Zond-12e GPR (Radar Systems, Inc., Riga) using several antennas with frequencies of the probing signal 1500 and 2000 MHz. The choice of antennas is due to the characteristics of the object under study, in particular the pitch of the reinforcement rods in the body of the plate, since if it is comparable to the length of the probing pulse, the reinforcement layer can act as a screen, which would lead to data loss.

Also, because the dimensions of the probable defects in the structure of the plate are unknown in advance, the use of a technique that provides the best resolution is optimal, which is achieved by reducing the length of the electromagnetic wave.

During visual inspection, horizontal joints were found on the side surface of the slab grillage, indicating the possible presence of "cold" concreting joints.

After processing the obtained data, the radarograms were analyzed to develop mapping features to highlight the main elements of the plate structure, zones of increased local moisture and voids.

The structure of the studied medium in the studied area, based on the available a priori information about the design device of the slab, can be approximated using a three-layer horizontally layered model: the upper layer is a monolithic concrete slab (capacity - about 120 cm); followed by a layer of preparation, represented by bulk sand materials; and the lower boundary - the surface of levelling the bottom of the pit (the roof of compacted bedrock - mainly loam). Thus, three main reflecting boundaries can be expected on GPR profiles: between the base of a monolithic concrete slab and an intermediate layer with waterproofing, and a layer of sand—the roof of the bedrock. They can be traced on radarograms in general quite confidently.

However, measurements by the method of GPR profiling on the surface of the upper surface of the plate grillage showed that the structure of the slab is heterogeneous. This is expressed in the presence of areas where internal reflecting boundaries are distinguished along the axes of the common phase of the reflected waves, interpreted as cold contact boundaries.

The results of the interpretation of all the obtained geo-radar profiles (Fig. 2) can be generalized into maps of the surfaces of horizontal concreting joints (Fig. 3), reflecting both the relief and the distribution of the identified defects in space. It is worth noting that the highlighted borders are not ubiquitous, which is easy to see on the presented maps.

In the process of manufacturing a monolithic reinforced concrete slab, violations were revealed, which consisted of increased intervals between pouring concrete. The expected depths at which violations occurred are 10–20 cm. At the same time, the expected inhomogeneities/voids may have dimensions of several centimeters. Two antennas with frequencies of 1500 and 2000 MHz were used for the study. A lower frequency antenna was used to study the entire plate in depth, and a higher frequency antenna was used for depths up to 60–70 cm.

Since these depths are targeted, data obtained using a 2000 MHz antenna was taken for interpretation. It is assumed that the physical properties of a monolithic slab are the same in the thickness of the slab itself.

Thus, on radarograms, the first boundary from which the reflection will occur will be the sole of the plate. However, on many radarograms there are several reflecting boundaries (Fig. 2), approximately at depths of 15, 25 and 50 cm. Also, the position of the reinforcement mesh is clearly visible on the radarograms. Two cold contact boundaries can be distinguished in the body of the foundation plate (Fig. 2): the first, at depths of 0.09 to 0.25 m; the second, at depths from 0.32 to 0.7 m, which was confirmed by control drilling with core sampling.

Based on the results of the analysis of the received radarograms, maps of the depths of the cold contact surfaces were constructed (see Fig. 3, 4).

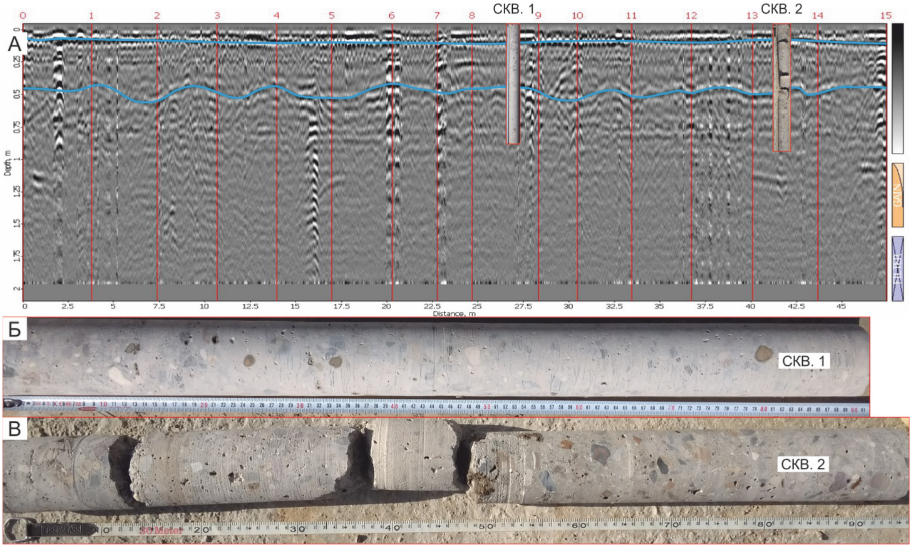

Fig. 1. Determination of cold contact boundaries: A - interpreted radarogram, B—core from hole 1, C—core from hole 2.

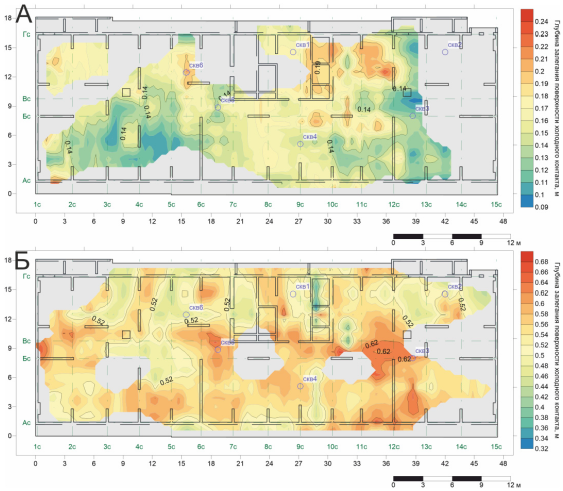

Fig. 2. Depth maps of the surfaces of the first (A) and second (B) cold contacts (independent color scales).

To clarify the data obtained from the GPR survey, cores Ø74 and 143 mm were drilled from the body of the plate grillage. Core drilling was carried out in areas with identified reflective boundaries. According to the results of the the drilling and extraction of core samples, the presence of “cold” concreting joints was confirmed in the areas and depths obtained during the GPR studies. Some samples fell apart into several parts. It is worth noting that the marked joints have an intact distribution. Additionally, during the study of the core chips, the presence of air cavities and traces of poor-quality compaction of the concrete mixture was noted.

The drilling carried out made it possible to bind the reflective boundaries. When analyzing the drilling results, differences in concrete up to a depth of 15 cm and deeper are clearly visible. It is also noticeable that the column has fallen apart into several parts. The study of the chip showed the presence of air cavities and chips. According to the results of the analysis of the data obtained, it was found that the reflecting boundaries coincide with the boundaries of core destruction.

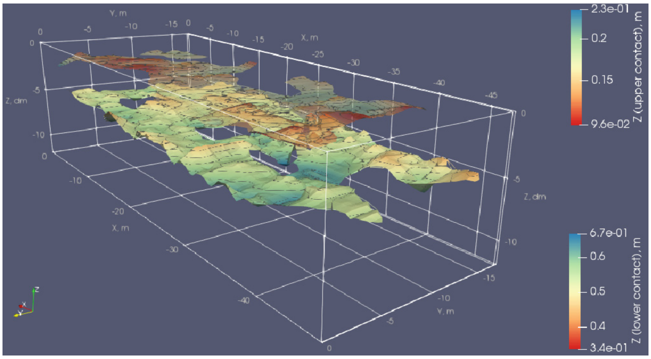

Fig. 3. Depth maps of the surfaces of the first (A) and second (B) cold contacts (independent color scales).

3.2 Foundation Slab #2

The foundation plate of a 15-storey residential building is 800 mm thick, reinforced with two meshes – upper and lower with main reinforcement Ø16 mm 200 × 200 mm. Vertical load-bearing structures (walls and pylons) are rigidly connected to the foundation plate by means of reinforcing connection bars. Vertical reinforcement against punching in the pylon zone is not required according to calculations and is not installed.

During the construction of the foundation slab, due to pauses in concreting, there was a suspicion of the formation of horizontal and inclined cold joints in the structure of the foundation slab. GPR scanning was performed using an orthogonal system of profiles, which showed the presence of reflecting boundaries in the structure of the foundation slab (Fig. 4).

To confirm the presence of cold concrete joints, a control drilling with core sampling was performed. Inspection of the drilled cores showed the absence of pronounced boundaries, that is, cold joints. To determine what the clearly visible boundaries on the radarograms relate to, a test of cylinder samples from drilled cores was carried out. The analysis of the test results showed that the samples from the upper layers of the foundation plate have a lower strength than the samples located deeper (see Table 1). Furthermore, the difference in unit strength values between the surface layer and depth can reach up to 37%! Thus, it was found that the visible reflective boundaries on the

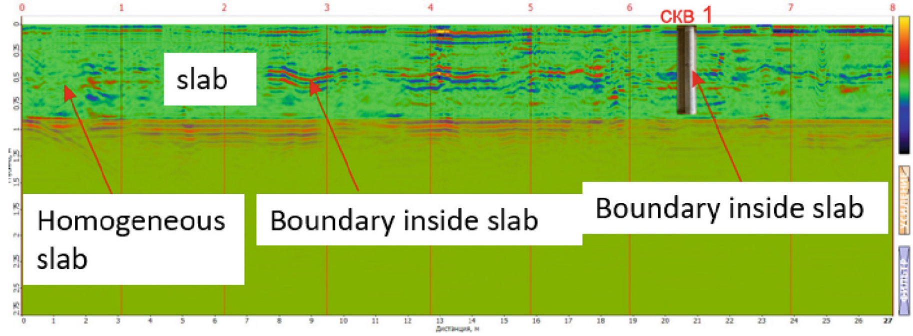

Fig. 4. A typical radarogram showing the boundaries in the structure of the foundation plate.

radar images are confined to concrete layers with different strengths, and not with the presence of cold concreting joints. This fact is explained by insufficient care of the concrete during the hardening period, and the upper layer did not gain the necessary strength due to the evaporation of moisture from the surface layers.

Radar images also showed areas of anomalies that are associated with increased cavity formation due to insufficient compaction of the concrete mixture during the concrete being laid. According to the results of the analysis of maps of cumulative amplitudes, areas with presumably increased cavern porosity are identified - see Fig. 5 (areas of greater amplitudes corresponding to zones of greater cavern porosity are highlighted in red).

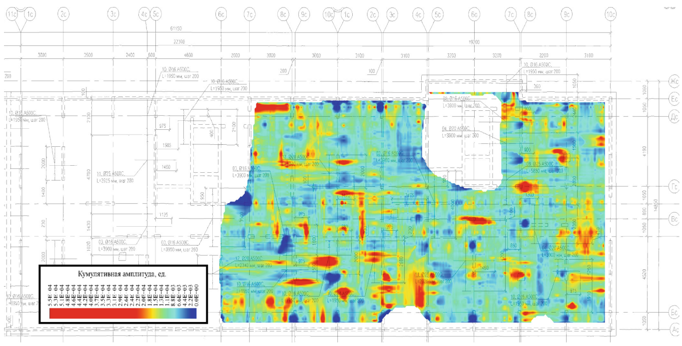

Fig. 5. Map of cumulative amplitudes for the depth range 0.35–0.72 m (red areas are presumably correlated with areas with increased porosity) (Fig. 6).

3.3 Roof Slab of Metro Station

The third object of the study is a roof slab of the Moscow metro station under construction. The plate has a thickness of 1 m with arranged beams along the axis of the columns. The slab reinforcement was made classical with lower and upper meshes, as well as vertical transverse reinforcement (stirrups). After concreting the structure, there was a suspicion of the formation of horizontal cold concreting joints.

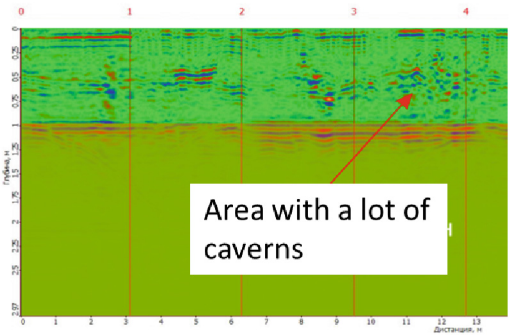

Fig. 6. Radarogram with areas of caverns joints.

Table 1. Compression testing results of specimens from foundation slab#2.

Strength, MPa				
№ cylinder	1	2	3	4
	18,8 (top)	17.3	19.1	19,0
	17,6	19.8	22.8	18,6
№ specimen	22,2	21.9	23.4	20,8
	27,9	27.8		19,7
	27,2 (bottom)	20.0 23.0		22,6 25,3
Average strength	22,7			
	21,6	21,7	21,0	

To check for the presence of cold joints, an orthogonal GPR examination was performed. According to the results of processing, several reflective boundaries were identified in the structure of the structure, which indicated the possible presence of cold concreting joints. As a result of data processing, a 3D picture of the spread of a cold concrete joint was built (Fig. 7). Drilling into the body of the roof slab confirmed the presence of several cold concreting joints. It should be noted that core drilling was complicated by the fact that it was carried out from the bottom up because the top of the roof slab was waterproofed. Considering the identified horizontal cold concreting joints, the FE analysis and calculation of the cold joint performed according to the SP337.1325800.2017 methodology.

According to the calculation, considering the available vertical reinforcement, the bearing capacity of the horizontal cold joint not provided, so the vertical reinforcement was designed and implemented in the form of deformed steel bars glued from below onto a chemical anchor. During real application of strengthening some difficulties with placement of vertical rebars were encountered because of the existing reinforcement mesh.

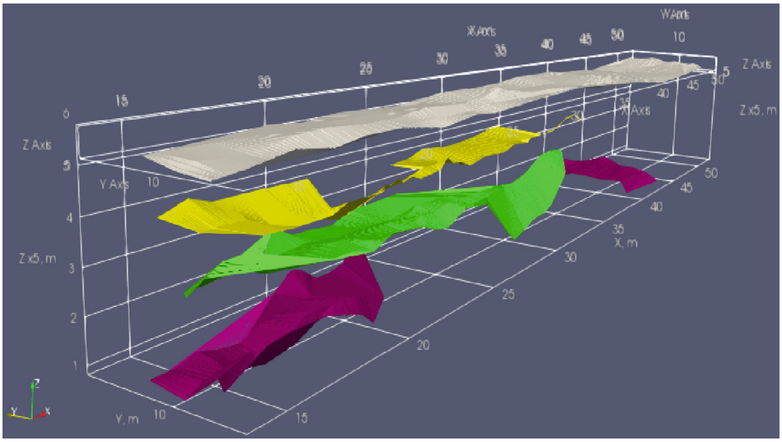

Fig. 7. A3D visualization of the roof slab with cold joints. Violet, first boundary; green, second boundary; Yellow, third boundary; grey, top surface of the roof slab

4 Conclusions

On the basis of the results of the conducted research, the following conclusions can be drawn.

1) The formation of undesired cold joints leads to non-monolithic RC structures, and such structure should be calculated for shear strength and, if necessary, strengthened.
2) Cold joints in slabs could be detected using GPR with appropriate frequency antennas and special approaches.
3) Using GPR, some other concreting defects could be identified, such as pores and caverns.
4) Sometimes not cold joints can be detected but the boundary between layers with different concrete strength (due to the insufficient curing of concrete).
5) More research is needed to investigate the influence of cold joints on the strength of reinforced concrete structures.
6) Design codes should better cover the issues related to cold joints in RC structures.

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