Determination of concreting quality of bored piles by CHA method

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Abstract. In the presented article, the authors consider the issues of quality control of bored piles in the practice of bridge construction. The importance of quality control of these pile structures is emphasized. The basic requirements for quality control in the production of construction works and their acceptance are presented. A description of the control method is given. As a practical example, the results of quality control of the execution of bored piles by the method of cross well ultrasonic scanning at the bridge over the river Chusovaya. An assessment of the state of bored piles after testing is given.

1. Introduction

The choice of the foundation design is made based on the conditions of the construction site, based on data obtained from the results of engineering-geological, engineering-hydrological surveys, calculated loads acting on the foundation, as well as based on a technical and economic comparison of options for possible design solutions, taking into account environmental and resource-saving requirements.

In construction practice, at high loads and the depth of occurrence of strong soils, bored piles (BP) are used, which are subdivided according to the method of the good construction, material and method of the barrel construction, geometric shape of the cross-section of the barrel, presence of a widened heel, position of the shaft axis to the horizon, by the location of the piles in the plan and by the nature of the work in the ground.

According to the data of the Belgian geotechnical engineer V. F. Van Impe, 22% of the piles used in construction are large and small diameter bored piles (figure 1) [1]. BP is used as a base in load-bearing and enclosing structures, as well as for the arrangement of underground structures. Bored piles are widely used in the foundations of bridge structures and other transport construction facilities.
The design and installation of bored piles are carried out by the requirements of the Formulary 24.13330.2011 «Pile foundations», Formulary 45.13330.2017 «Earthworks, foundations, and foundations», Formulary 63.13330.2018 «Concrete and reinforced concrete structures. Basic provisions». Loads and impacts, their combinations, reliability factors, and operating conditions are determined following the requirements of Formulary 20.13330.2016 «Loads and impacts» and industry design standards.

During the construction of bored piles, the load-bearing capacity increases due to compaction and reducing the deformability of the near-pile soil [2]. In the manufacture of BP, the required technological mode of the compacting effect on the laid concrete mixture, crushed stone, and near-pile soil is provided by special hydraulic equipment. The technology is based on the method of deep volumetric vibration impact on the compacted materials. The design parameters of strength, frost resistance, and water resistance are provided by assigning the optimal composition of the concrete mixture.

2. Theoretical part
The production of BP with violations of the technology can lead to the formation of defects that reduce the load-bearing capacity and durability of structures, which jeopardizes the safety of structures. Production and quality control of works is carried out under the technical regulations developed for a specific object.

To control the quality of the work performed on the BP device, it is difficult to apply direct methods of studying the strength of concrete. In this regard, indirect non-destructive methods (seismic acoustic, thermometric, ultrasonic, etc.) have become widespread, which makes it possible to conclude the quality of concrete piles by analyzing the parameters of physical fields of various nature [3, 4, 5]. The ultrasonic method has been used to control the continuity of concrete bored piles since the late 1960s. The application of the method is regulated by documents adopted in many countries of the world, including the ASTM D6760 standard [6].

According to [7], in the process of bridge construction, the contractor should carry out works of post-operational control of construction and installation.

Operational and acceptance control of the quality of the drilling pile device is carried out by the technical requirements specified in table 6 of the Formulary and includes a measuring method and a non-destructive ultrasonic control method.
Following the requirements of [7], at least 30% of the piles in the pile cap of each support (but not less than four) or 100% of the piles in the supports without pile cap should be tested by the ultrasonic method (USM). Non-destructive testing of the concrete continuity of deep foundation piles by the ultrasonic method is based on determining the parameters of ultrasonic waves (propagation velocity and attenuation) propagating between special tubes installed in the reinforcement cage to conclude the continuity of the concrete structure (figure 2). The standard speed of propagation of ultrasonic waves in the concrete of the required quality is 3500-4500 m/s. If the pile contains foreign inclusions (soil, sludge material, water, bentonite, voids, etc.), this will lead to a local decrease in the propagation speed of ultrasonic waves and an increase in the attenuation values of the recorded signal. Ultrasonic testing allows controlling the continuity in extended structures (piles, walls, columns, etc.) with localization of defects, to determine the strength of concrete in various parts of the structure.

Studies of bored piles by the ultrasonic method make it possible to detect areas of concrete discontinuity located within the planes between the axes of the access pipes, localize them in-depth and assess their location within the cross-section of the pile.

Figure 2. Non-destructive testing of concrete continuity of foundation piles: 1 is pile body, 2 is signal transmitter, 3 is signal receiver, 4 is position sensors, 5 is device, 6 is defect.

The size of the abnormal zones that can be detected by the method is comparable to the wavelength and depends on the center frequency of the ultrasonic transducers, the position of the zone within the controlled area, the distance between the access pipes, the physical properties of the zone, etc. [8]. Anomalies in the parameters of ultrasonic waves can be caused not only by the discontinuity of the concrete of the structure but also by the disruption of contact (voids) between the access pipes and the concrete in the upper part of the structure, the inclination of the access pipes relative to the axis of the pile reinforcement cage and other reasons [9].
Ultrasonic tests are carried out using the parallel-sounding technique. A source of ultrasonic waves is immersed in one access pipe to the lower mark, and a receiver for ultrasonic waves is immersed in the other (figure 2). The source and the receiver are simultaneously lifted and, with a predetermined step, excite and record ultrasonic signals. Concrete continuity control is performed for each pair of access pipes installed in the structure. The recorded data is transferred to a personal computer for further processing and visualization in the form of graphs of changes in speed and attenuation versus depth and "waterfall" diagrams [6, 9].

3. Object of study
Characteristics of the object. The bridge crossing over the river Chusovaya (new part of the bridge) (figure 3). The class of the building is three; the level of responsibility is increased. Loads from rolling stock А14 and Н14 according to Formulary 35.13330.2011. The last support No. 1 is non-grated with a monolithic nozzle.

![Figure 3. The layout of the bridge.](image)

The foundation of support No. 1 is taken from bored piles with a diameter of 1420 mm, a length depending on geological conditions of 37.5 m, with a non-retrievable casing electric-welded longitudinal seam pipe Ø1420 x 16 mm made of steel mark ST3SP2 (see table 1). The concrete piles are heavy hydraulic engineering, compressive strength class B25, frost resistance grade F300, water-resistance W6 according to Interstate standard 26633-2015. Reinforcement of the piles is provided by space frames made of reinforcement of periodic profile A400 Interstate standard 5781-82 from steel mark 25G2S and rod reinforcement hot-rolled smooth A240 Interstate standard 5781-82 from steel mark ST3SP. The number of piles in support No. 1 is 6 pcs (figure 4).

Before concreting the piles, it is envisaged to strengthen the bottom of the wells with M800 crushed stone of fraction 20-40 mm (Interstate standard 8267-93) using the Vibropost technology. The connection of the piles with the nozzle is taken rigidly - the top of the piles is sealed 100 mm, the outlets of the working reinforcement of the piles are 1000 mm.

| Pile number | Concreting date | Pile diameter, mm | Actual pile length, m | The actual elevation of the top of concrete, m | Pile bottom elevation, m |
|-------------|-----------------|-------------------|-----------------------|---------------------------------------------|-------------------------|
| 01.01       | 16.09.2019      | 1420              | 38.450                | 117.852                                     | 79.402                  |
| 01.03       | 07.09.2019      | 1420              | 37.952                | 117.348                                     | 79.396                  |
| 01.05       | 17.09.2019      | 1420              | 14.500                | 93.940                                      | 79.440                  |
Figure 4. Location of piles in the foundation of support No. 1.

The test of continuity by the method of ultrasonic diagnostics was carried out in piles 01.01, 01.03, and 01.05 of the foundation of the support No. 1. For ultrasonic inspection in piles, there are three metal tubes with a diameter of 159 mm (1 piece) and 57 mm (2 pieces) (figure 5). The tubes are filled with water before testing.

Figure 5. Arrangement of tubes for ultrasonic inspection.

4. Experimental technique
The CHAMP (Cross-Hole Analyzer) ultrasound monitoring device (figure 6 (a)) and Pile Dynamics specialized software was used to measure and analyze the continuity of bored piles.

CROSS-HOLE-ANALYZER (CHA) is a defect score that uses the inter-important acoustic study method to determine the quality and consistency of concrete between pairs of pipes pre-installed in the pile body. The CHAMP device works in a fully automatic mode with the specified pile parameters, gives preliminary results directly when measurements in real-time, so it is excluded errors and falsification of the operator [10].
Specifications. Size 115 mm x 190 mm x 240 mm. The range of working temperatures from 0 to 40 degrees Celsius. Powered by an internal battery designed for 5 hours of data collection mode. Scanning speed up to 1.5 m / s with a sampling rate of 500 kHz. The scanning step during the experiment was taken 50 mm.

The device works with dual high-resolution position sensors to independently determine the depth and direction of the probes. For maximum accuracy, position sensors can be installed directly on piles (figure 6 (b)).

After processing the measurement results using specialized software (CHA-W), with a sufficient number of sections, a 3D model of the pile with identified defects can be built. CHA-W guarantees complete recording of all signals and data collection from all pipe combinations.

Figure 6. Checking the BP continuity by ultrasonic inspection: (a) CHAMP device; (b) pile checking.
According to the measurements, the rate of sound wave propagation in the piles of 01.01 varies from 2230 to 5120 m/s, in the pile 01.03 from 3050 to 5700 m/s, in the pile 01.05 from 2200 to 5050 m/s. The results of checking the pile continuity are shown in figures 7 to 9.

The continuity of the bored piles is ensured, minor defects in the pile shaft will not affect the bearing capacity.

Figure 7. Results of checking the continuity of the pile 01.01.

Figure 8. Results of checking the continuity of the pile 01.03.
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5. Conclusions

Ultrasonic testing of the concrete continuity of the bored pile shaft makes it possible to determine and localize defects in the concreting of the pile shaft. However, this method requires additional piping and is more expensive. When choosing a method, one should take into account the required completeness of the obtained data on the continuity of concrete in bored piles. At the first stage, the seism acoustic method should be used as the cheapest and not requiring additional costs. If defects are detected, their position should be determined by drilling out cores. If it is supposed to use the ultrasonic method in the manufacture of piles, it is necessary to provide installation of additional tubes, which will avoid coring. The most reliable determination of the presence and type of concrete discontinuity in the bored pile shaft is made possible by core drilling. The application of this method is limited by the high cost of work, as well as the need to eliminate cavities after core extraction.

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