Measuring the Strength of Concrete in the Underwater Part of Hydraulic Structures

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Abstract. Devices for nondestructive testing of concrete strength (separation with chipping, ultrasound, elastic rebound method) allow to measure the strength only in the air. But for inspecting hydraulic structures (for example, piles of berths), it is necessary to measure the strength of concrete under water. For this purpose, it is possible to use the method of plastic deformation using a shotgun as a percussion device for spearfishing while providing a constant (controlled) force of impact. The works described in the article on obtaining special calibration dependences allowed to successfully apply the method of plastic deformation for measuring the strength of concrete in the inspection of piles of berths in the Black, Barents and Okhotsk seas.

1. Introduction
Measuring the strength of concrete is one of the main functions in assessing the condition of reinforced concrete structures during their examination [1, 3, 4, 6, 7, 10, 11, 15]. Modern devices for determining the strength of concrete by non-destructive methods (tearing with chipping, ultrasound, elastic rebound) provide the necessary accuracy of measurements, but are intended only for measurements in the air [2, 5, 8, 12, 13, 14]. There are no devices for measuring the strength of concrete under water.

When inspecting hydraulic structures, the greatest need is to assess the strength of concrete in the zone of variable water horizon and in the underwater zone close to the water surface, where concrete works in the most adverse conditions [9, 16]. This is due to the alternate wetting and alternate freezing and thawing of concrete in a water-saturated state. The most quickly destructive processes occur in the Northern seas in the formation of ice cover in winter and in the tidal zone in all climatic zones [1, 9, 17]. Therefore, the supporting structures of marine hydraulic structures require regular inspections with mandatory control of the strength of concrete [2, 3, 18, 19].

When carrying out inspections of the piles of the piers we have used conventional non-destructive inspection (ultrasonic device 1401 of the criminal code, sclerometer SilverSchmidt N-type), placed in sealed plastic bags when performing measurements in the underwater area and the PM hammer method (plastic deformation) and ONYX (method of separation with shear fracture).

To date, the only non-destructive testing method that can be used without prior calibration (direct measurement) is the chipping separation method. When using this method, the calibration dependence is specified by introducing coefficients that take into account the size of the filler and the
type of concrete – heavy or light. The method is quite widespread [20]. However, according to laboratory studies [21] at high intensity of reinforcement of monolithic reinforced concrete structures, the result of the strength of concrete, measured by separation with chipping, is not accurate, because often the scheme of destruction of the concrete surface occurs on the reinforcement cell. At the same time, this method requires significant labor costs, damages the concrete and therefore this method performs a small number of measurements with significant variations in the readings. Practice shows that the use of the method of separation with chipping for calibration of ultrasonic devices and sclerometers does not provide the required accuracy. However, when we used this method to control the strength of concrete piles of berths in Korsakov in the zone of variable water horizon, the dispersion of measurement results was much less than when using other methods of non-destructive testing. Unfortunately, the use of this method to control the strength in the underwater zone is almost impossible.

The greatest dispersion of indications occurred when using the ultrasonic method for strength measurements in the underwater zone, as well as when using the method of elastic rebound in the zone of variable water horizon. Measurements were correlated with the existing generalized calibration dependencies. Attempt to execute a correction of the calibration dependencies for these devices have not been successful.

The low accuracy of strength measurements when using these methods is primarily due to the existing damage (peeling) of the surface layer of concrete in the zone of variable horizon and in the underwater zone close to the water surface. Said confirmed special study: after performing the measurement method of elastic rebound in a particular area in the variable area of the horizon surface of the concrete at the site were cleaned with emery grinder, and then re-performed the strength measurements. The measurements made after surface cleaning had smaller dispersion and better correlated with the specified calibration dependence.

The highest reliability of the measurement results obtained by applying the method of plastic deformation, as there is less impact of the thin surface layer of concrete having damage. This method is based on measuring the size of the imprint that remains on the surface of the concrete after the impact of a steel ball. The method is outdated, but it is still used because of the simplicity and cheapness of the equipment. The most widely used for such tests Kashkarov’s hammer or spring hammers of various designs. In the zone of variable horizon, we used hammers PM and Kashkarova, and underwater zone-hammer Kashkarova with twice the mass of the hammer used to strike. Obtaining the highest reliability of the measurement results using the method of plastic deformation has necessitated its improvement with the use of new tools to determine the strength of concrete in the underwater zone of marine hydraulic structures.

2. Methods
During the survey of piles in the ports of the Black sea, we have tested a method of measuring the strength by plastic deformation with a pneumatic gun for spearfishing. At the same time, special studies were carried out, which allowed to obtain calibration dependences that provide the necessary accuracy of measurements.

To ensure a constant (given) the force of impact to the front of the gun was fixed focus, providing shot strictly from a distance. The length of the stop at 20 cm exceeded length of the harpoon. As a strike tip to the harpoon is fastened to the bead diameter of 17.5 mm. For measuring the diameter of the hole under water used angular range.

The necessary force of impact was selected so that the diameter of the imprint was from 4.5 to 13 mm (from 1/4 to 2/3 ball diameter) in the measured range of concrete strengths. Given a constant force stroke (the initial velocity of the harpoon) provided the measurement of the dynamometer ultimate harpoon press force into the barrel. The constancy of the crushing force was ensured by regulating the air pressure in the pneumatic chamber of the gun.

It is known that the strength measurement by plastic deformation is performed on the dry surface of concrete, since the water saturation changes the correlation between the strength and hardness of
concrete. In the construction of calibration dependencies tested cubes (which are struck and then tested on the press) require mandatory pre-drying. If the measurements are carried out at the wet surface of the concrete, the obtained (according to the calibration dependence) strength value is multiplied by a factor of 1.4. At the same time, the accuracy of strength determination decreases significantly. Therefore, it was not possible to use the accumulated information (generalized gradations).

3. Results

To obtain reliable data on the strength of concrete in the underwater part, special calibration works were performed using a gun, which was used when striking piles with subsequent measurement of holes. Construction of calibration dependences was performed in Moscow (ZNIIS), in Murmansk and in the concrete laboratory in determining the strength of concrete piles of the wharves in the city of Korsakov (Sakhalin island). Cubes measuring 15x15x15 cm of different strength were kept under normal conditions from 7 to 28 days and then placed in sea water to a depth of 1 m. Tests were carried out after being in the water from 7 to 14 days. When you strike cube (shot) his back was against the wall of the pool (or tank with sea water) gun point-blank at the depth of 0.4 m. On each side the brink was applied on three hits. After removing the cube from the water and measuring the diameter of the holes with a large spread of indications (errors), it was again lowered into the water and applied additional blows. Testing of cubes on the press was carried out in a water-saturated state immediately after measuring the diameters of the holes. Taking into account the known data on the difference in the strength of different layers of water-saturated concrete in some cubes, impacts were also applied after the removal of the surface layer with a thickness of one to five millimeters. According to the results of these tests, the coefficient equal to 1.25 for cubic strength using the method used. One of the obtained calibration dependences is presented in fig. 1.

![Figure 1. Calibration dependence:](image)

1-for dry concrete;
2-for concrete saturated with sea water.

The calibration curve obtained in Korsakov has been refined by drilling-out and testing of cores from the piles, which was discovered lying at the bottom beneath the jetty at a depth of 1.5 m. Before extracting the piles out of the water on it was hit more than 20 times.
Most of the underwater strength measurements were performed at depths ranging from 0.2 to 2 meters when examining piles of berths in the Black, White and Barents seas. In the sea of Okhotsk measurements were made at depths of 0.2 to 8 meters. At the same time, it was found that the strength of concrete remains unchanged at depths of 1 to 8 meters. At a depth of 0.2-0.4 m, the strength reduction, as a rule, ranged from 10 to 30%. The lowest strength values are obtained in the upper part of the variable horizon zone or directly above the water level (with minor level fluctuations). The destruction of concrete in this zone was recorded not only in the Barents and Okhotsk seas, but also in the Black sea. Reinforced concrete piles experienced pier in Murmansk fracture of concrete along the entire cross section at 50% of the piles demanded the demolition of the pier in 3 years since construction. Korsakov some of the piles of the pier, operated for 8 years recorded the destruction of the surface layer of concrete to main reinforcement. In the Black sea (G. Ilyichevsk) mass destruction of the surface layer of concrete was recorded in May after an abnormally cold winter in piles, which were manufactured and shipped (shock method) in October-November just before the onset of negative temperatures.

4. Conclusions
1. The method of plastic deformation can be used to measure the strength of concrete in the underwater part of hydraulic structures while providing a constant (predetermined) force of impact, which must be maintained during the excavation work.
2. It is possible to use the ultrasonic method for this purpose, provided that the device is sealed in direct contact with the surface of the concrete probes. At the same time, research is needed to establish a method of measurement and construction of calibration dependences.
3. Evaluation of the strength of concrete by plastic deformation in the underwater part of hydraulic structures should be performed by measuring the strength in two layers: the surface and at a depth of 3-5 mm (after removal of the surface layer).
4. Measurement of concrete strength of the piles, submerged percussion techniques performed prior to pile driving, after her and 7-15 days after immersion showed that the dynamic tension force in driving, the vast majority of cases, lead to microseminoprotein and loss of strength of concrete. The resulting microdefects are largely healed within 15-20 days when in fresh water. In contact with sea water, the resulting microcracks contribute to the corrosion of the reinforcement. An effective measure to prevent corrosion is to coat the watertight mastic of the upper part of the pile in contact with sea water before sinking the pile.

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